FINAL REPORT

MONITORING AND EVALUATION OF COASTAL HABITATS FOR POTENTIAL RESTORATION ACTIVITIES

To
David Kenaga, Project Manager
Michigan Coastal Management Program, Land & Water Management Division,
Michigan Dept. of Environmental Quality
Progress on MDEQ Grant 02-309-01a (GVSU Ref. 4-26507)
(AWRI Publication #TM-2003-19)

Donald G. Uzarski & Matthew J. Cooper
Annis Water Resources Institute
Lake Michigan Center
Grand Valley State University
740 W. Shoreline Drive
Muskegon, Michigan 49441

Thomas M. Burton
Departments of Zoology and Fisheries and Wildlife
Michigan State University

Dennis A. Albert
Michigan Natural Features Inventory
Michigan State University – Extension

Introduction

Wetlands in the coastal zone of the Great Lakes have been converted to agriculture, urban, and suburban land uses since the 1800's with losses of more than 50 % of wetlands since European settlement of Michigan began (Dahl 1990, Comer et al. 1995). These losses are continuing for certain types of wetlands (Dahl 2000) and, perhaps, accelerating with the recent trends in urban sprawl. As losses of relatively pristine lands in private ownership occur, greater pressure is placed on publicly owned lands to provide habitat for wildlife, serve as repositories of biodiversity including protection of threatened and endangered species, and provide recreational opportunities for Michigan citizens including hunting, fishing, bird watching, wildlife viewing, etc. Thus, there is a need to: (1) identify converted or disturbed wetlands sites in public ownership that are suitable for restoration, (2) identify critical publicly owned high quality wetlands in the coastal zone so that managers can place a high priority on sustainable management of them, and (3) collect baseline data on biota of these wetlands to document their value and serve as a basis for comparison of their biotic integrity in the future.

Coastal wetlands originally formed an almost continuous fringe along much of Saginaw Bay and many other bays and shallow coastal areas of the Great Lakes shoreline (Comer et al. 1995, Minc 1997, Minc and Albert 1998, Keough et al. 1999). Only about 50 % of Great Lakes coastal marshes remain relative to historical estimates. The decline has resulted primarily from intensive land conversion and settlement within the Great Lakes basin, especially for the lower Great Lakes (Comer et al. 1995). Approximately 65,547 ha of coastal wetlands remain on the upper Great Lakes, with major complexes including Saginaw Bay (12,140 ha) and Georgian Bay (12,600) of Lake Huron and Green Bay (9,980 ha) and Big Bay de Noc (7,720 ha) of Lake Michigan (Prince et al. 1992). Despite the fairly extensive and numerous isolated complexes that remain, many aspects of the ecology of these systems remain poorly understood.

Several researchers have provided evidence that Great Lakes coastal marshes provide critical habitat for invertebrates, fish, birds and other species (see reviews in Krieger 1992, Jude and Pappas 1992, and Prince et al. 1992, Wilcox 1995, and Gathman et al. 1999). Prince et al. (1992) described coastal wetlands as important feeding and nursery habitats for waterfowl. Many species of Great Lakes fish feed heavily within coastal wetlands during at least some part of their life cycle (Brazner 1997, French 1988, Jude and Pappas 1992, and Liston and Chubb 1985). These studies suggest that coastal wetlands are critical habitats and nursery areas for maintenance of primary and secondary production in the Great Lakes. Despite the potential contribution of these wetlands to overall ecosystem function, research linking physical and floristic characterization of Great Lakes marsh types to the fauna is limited for Great Lakes coastal wetlands, especially for the wetlands inland of the mean high water mark.

For more than a decade, we have collaborated with several other researchers to systematically sample Lake Huron and Michigan coastal wetlands and explore many of the dominant characteristics of coastal wetlands that may be important structuring forces for plant, invertebrate, fish and bird communities. This research has resulted in numerous reports (e.g. Albert et al. 1987, 1988, 1989, Prince and Burton 1995, Minc 1997, Chow-Fraser and Albert 1998, Minc and Albert 1998, Gathman and Keas 1999), theses and dissertations (e.g. Brady 1992, 1996, Cardinale 1996, Whitt 1996, Young 1996, Kashian 1998, Gathman 2000, Riffell 2000, Stanley 2000, Vaara 2001), and refereed papers and book chapters (e.g. Brady and Burton 1995, Brady et al. 1996, Cardinale et al. 1997, 1998, Gathman et al. 1999, Kashian and Burton 2000, Burton et al. 2001, Riffell et al. 2001a, 2001b). This work has allowed us the opportunity to describe the communities from a diversity of habitats and begin to identify potential mechanisms contributing to the community composition.

In this report we define ‘coastal wetlands’ as including: (1) the fringing wetlands extending from the shore into the littoral zone of the Great Lakes, (2) the riparian wetlands along rivers and drowned river-mouth lakes that are potentially influenced by short-term (seiche and storm surge induced) changes in water levels, and (3) marshes and swamps in the coastal zone inland from the lakeshore that are not directly affected by short term water level changes in the Great Lakes. Before this project began, the majority of our research to date has emphasized the fringing, littoral and riverine wetlands with direct surface water connections to the Great Lakes, although some research on coastal zone wet meadows and other types of wetlands not directly connected to the lakes has been included (e.g. Burton et al. 2001 (in press), Stanley et al. 2000, Riffell et. al. 2001a, 2001b). Unlike the adjacent littoral marshes, the inland marshes and swamps are not directly exposed to waves, storm surges, or seiches, since they are only connected to the Great Lakes via subsurface water movements in most years. However, water level changes in the inland, coastal zone wetlands may be influenced by lake levels either through direct exchange of water via subsurface movements through sandy and other relatively porous soils or through changes in direction and rate of groundwater movements as lake levels influence depth of the water table in the coastal zone. Groundwater inputs from adjacent upland areas also influence these coastal zone wetlands and make them important transition zones between uplands and littoral wetlands.

With increased restoration efforts and funds, there is a great opportunity to begin restoring swamp forest, the component of coastal wetlands that saw the greatest level of elimination in the past (Comer et al. 1995), and to restore the mixed wetland/upland habitat that supports high biodiversity in the coastal zone of the Great Lakes. Swamp forest, lakeplain wet prairies and wet meadows were the coastal wetlands most easily converted to agricultural management, requiring less drainage than deeper emergent marshes. Once drained, these former wetlands also flooded less frequently than drained coastal marshes. Thus, little farmland created in this zone has been abandoned and allowed to return to functional wetland. One of the goals of this project was to sample coastal swamps and depressional wetlands in an effort to provide baseline data on biota characteristic of these sites. A second goal was to use our findings to identify sites in public ownership that have high potential for restoration. We used bioassement protocols to obtain baseline data while also providing us with a measure of anthropogenic disturbance a particular system is experiencing. We used these biotic data in conjunction with chemical/physical and land use/cover data to further develop our indices of biotic integrity.

We have developed a macroinvertebrate based bioassessment procedure for coastal wetlands in Michigan (e.g. Burton et al. 1999, Kashian and Burton 2000, Uzarski et al. submitted, also see summary report from the BAWWG web site (http://www.epa.gov/owow/wetlands/bawwg/case.html, the bioassessment wetlands working group organized by U.S. EPA)). Wilcox et al. (2002) attempted to develop wetland IBIs for the upper Great Lakes using macrophytes, fish, and microinvertebrates. Some of their metrics showed promise, but they concluded that natural water level changes were likely to alter communities and invalidate metrics. We have developed macroinvertebrate based IBI’s that take into account the fluctuating water levels of Great Lakes coastal wetlands by sampling within distinct plant community zones and basing the IBI only on inundated zones. We are confident that our macroinvertebrate IBI is valid under a wide range of water levels (e.g. Uzarski et al. submitted). We are working on fish and plant based metrics that can be adjusted over water level changes and believe that a viable IBI can be developed based on these taxa as well.

Minns et al. (1994) applied Karr's approach of using fish as indicators of stream biotic integrity (e.g., Karr 1981, Karr et al. 1986) to marshes of the Great Lakes' Areas of Concern. The metrics employed by Minns et al. (1994) were sensitive to impacts on ecosystem integrity by exotic fishes, water quality changes, physical habitat alteration, and changes in piscivore abundance related to fishing pressure and stocking. Even though several authors and SOLEC 1998 have suggested use of fish as indicators of wetland ecosystem health for Great Lakes coastal wetlands, no widely accepted system for wetland evaluation based on fish has been developed. Our work and the work of Brazner (1997), Brazner and Beals (1997),Minns et al. (1994) and Thoma (1999) suggests that IBI development should be relatively straight-forward. Our data presented here appear very promising.

The objective of this study was to sample several wetlands in two areas of Lake Michigan (those associated with eastern Lake Michigan drowned rivermouth wetlands and northern Lake Michigan fringing wetlands from the Straits of Mackinac to the Michigan shoreline of northern Green Bay including Little and Big Bay de Noc) and three areas of Lake Huron (Saginaw Bay, Thunder Bay, and Les Cheneaux Islands) to adequately characterize the flora and fauna to provide a baseline for restoration of wetlands in the coastal zone while quantifying the amounts of disturbance each system had already experienced. We also continued development and testing of indices of biotic integrity based on plant, invertebrate and fish communities that can be used to assess condition of existing sites and serve as a basis for measuring success of wetland restoration efforts in the coastal zone after they are undertaken. I will report on a portion of these data while Drs. Burton (MSU) and Albert (MSU-E) will report on the remaining. Dr. Albert will cover all of the macrophyte data. We obtained additional funding from the Michigan Great Lakes Protection Fund, US EPA, and he Great Lakes Commission. We were able to use these dollars to increase the amount of data that we were able to collect from fringing wetlands of the Great Lakes. We also partnered with Environment Canada (Joel Ingram) and Bird Studies Canada (Steve Timmermans) to obtain data from all five Great Lakes. We included the fish data from the partnership in this report.

Methods

Great Lakes Lacustrine Site Selection

We tested and developed indicators at open lacustrine and protected embayment wetlands while collecting baseline data for potential restoration purposes from selected wetlands along U.S.A. public shorelines of Lakes Huron and Michigan. We listed all potential sites using lists compiled in Chow-Fraser and Albert (1998) and/or open lacustrine and protected embayment sites listed by Herdendorf et al. (1981a-f) that were easily accessible (wetlands too far from an access point were eliminated from consideration). Since we suspected that many small wetlands were no longer inundated, we made site visits to all potential sites during June 2002 to determine which sites still had inundated wetlands present. We sampled all of the inundated, accessible sites during June, July and August of 2002. We collaborated with Joel Ingram of Environment Canada and Steve Timmermans of Bird Studies Canada to provide fish data from 25 more sites on Lakes Erie and Ontario. While these sites are not candidates for restoration, they do provide valuable information that can be applied to wetland ecosystems basin wide. Michigan wetland sampling sites sampled in 2002 are shown on the map in figure 1a.

Great Lakes Palustrine Site Selection

Site were selected based on proximity to the Great lakes as well as access through public lands. I will report on data collected from 10 such sites located in the coastal zone of eastern

Lake Michigan. Sample sites are shown on the map in figure 1b. Drs. Burton and Albert will report on the remaining palustrine sites located in the coastal zone.

Sampling Procedures

Description of Our IBI Development Methodologies Used from 1997-Present

Wetland Classification - Wetlands of the Great Lakes were classified into geomorphological classes that reflected their location in the landscape and exposure to waves, storm surges and lake level changes. We continued to categorize wetlands when obtaining baseline data and develop indicators from biological attributes unique to each class for each lake and/or ecoregion. However, we strived to explore similarities across classes and develop metrics that can extend across wetland types, lakes, and ecoregions. Sites sampled in 2002 are listed in table 1.

Open (lacustrine) wetlands were subdivided or analyzed along a continuum of exposure to wind and waves (Burton et al. 2001, Uzarski et al. submitted). These wetlands tend to form along bays and coves and leeward of islands or peninsulas. The more open the shoreline, the more energy the wetland is exposed to from waves and storm surges until a threshold is reached where wetlands can no longer persist. Our initial faunal research in Lake Huron suggests that a system can be developed that applies to all lacustrine wetlands despite the natural exposure gradient. However, the variation due to the exposure gradient must be accounted for when applying the sampling protocol. The location of the shoreline with respect to longshore current and wind fetch determines the type of wetland found along the shoreline (Burton et al. 2001), and there are marked differences in the preponderance of wetland types from Great Lake to Great Lake that we had to consider during data collection and development of indicators.

Great-Lakes wide studies of aquatic macrophytes indicated that similar geomorphic wetland types support distinctively different plant assemblages in geographically distinct ecoregions (Minc 1997, Minc and Albert 1998 (in press), Chow-Fraser and Albert 1998). Since our protocol is based on sampling all existing plant zones, we may eventually need to refine or adjust our IBI based on plant community distribution. Further resolution of classification is defined within our sampling protocol and our IBIs by including metrics to be used only under specific circumstances. For example, a suite of metrics are developed for use in wave swept bulrush zones of unprotected coastal wetlands, and these metrics may or may not vary from those to be used where dense vegetation or a peninsula dampens direct wave action in the same class of wetlands.

Chemical and Physical Measurements- Basic chemical/physical parameters were sampled at each time biological samples were collected. Analytical procedures followed procedures recommended in Standard Methods for the Examination of Water and Wastewater (APHA 1985). These measurements included soluble reactive phosphorus (SRP), nitrate-N, ammonium-N, turbidity, alkalinity, temperature, DO, chlorophyll a, redox potential, and specific conductance. Quality assurance/quality control procedures followed protocols recommended by U.S. EPA.

Determination of Anthropogenic Disturbance - Wetlands that experience a wide range of anthropogenic stressors were chosen from each class or subclass. The extent of disturbance was determined using surrounding land use data in conjunction with limnological data and site-specific observations of evidence of dredging, point-source pollution, etc. Land use data was obtained from existing digitized maps (MIRIS 1978), topographic maps, and personal observations. These data included such basic parameters as: percent urban and agricultural area, number of adjacent dwellings, percent impervious surface, and number of connecting drainage ditches.

Macroinvertebrates sampling - Macroinvertebrate samples were collected with standard 0.5 mm mesh, D-frame dip nets from June through August. Drowned river mouth systems were sampled during June and the remaining systems were sampled during July and August. Vegetation in drowned river mouth systems tends to establish earlier due to the relatively warm runoff that these systems receive. Samples taken from ice-out through May generally contain less diversity and a greater proportion of early instars of aquatic insects, making identification very difficult.

Macroinvertebrates were sampled from all major plant zones at each site, including an emergent zone and a wet meadow zone if it was present and inundated. If certain depths contained more than one dominant plant species or plant association, invertebrates were sampled in each.

Dip net sampling entailed sweeps through the water at the surface and middle of the water column and above the sediment surface to ensure that an array of microhabitats were included. In the field, samples were placed in white pans and 150 invertebrates were collected by picking all specimens from one area of the pan before moving on to the next. Special consideration was made to ensure that smaller organisms were not missed, as there is a bias towards larger more mobile individuals using this technique. Plant detritus was sorted for a few additional minutes to ensure that sessile species were included in the sample. As a means of semi-quantifying samples, specimen picking was timed. Individual replicates were picked for one-half -person-hour, after which, if 150 specimens were not obtained, organisms were tallied, and picking continued to the next multiple of 50. Three replicate samples were collected within each plant community zone in order to obtain a measure of spatial variance within each plant zone.

Specimens were sorted to lowest operational taxonomic unit; this was most often genus or species. Taxonomic keys such as Thorp and Covich (1991) and Merritt and Cummins (1996), along with mainstream literature for species level, were used for identification. Accuracy was confirmed by expert taxonomists whenever possible.

Fish sampling - Fish sampling was conducted using fyke nets with 12.5 mm or smaller mesh nets in each vegetation zone for one net-night. Two sizes net sizes were used, 0.5 m x 1.0 m and 1.0 m x 1.0 m. Smaller nets were set in water approximately 0.25 m deep to 0.50 m, the larger nets were set in water depths greater than 0.50 m. Nets were set adjacent to vegetation zones of interest with leads extending into the vegetation.

Initial work to identify and combine metrics into an IBI Initially, correspondence analyses of invertebrate and fish community composition was used to determine if reference sites separate from impacted sites. When they did, individual taxa containing the most inertia responsible for the separation were deemed potential metrics. Mann-Whitney U tests were then used to determine if densities of these taxa at reference sites were significantly different from densities at impacted sites.

Attributes that showed an empirical and predictable change across a gradient of human disturbance were chosen as metrics and included in our multi-metric IBI. Pearson Correlation analysis was also used to link state with stressor by relating potential metrics to specific parameters impacted by anthropogenic disturbance. Finally, stressor-land use relationships were explored to aid in management decisions.

We used medians in place of means for measuring assemblages of invertebrates, since invertebrate parameters are highly variable. Medians are more resistant to effects of outliers. Our goal was to typify the wetland. If an area was sampled that was depleted or concentrated in the constituents of a metric, the area may have been isolated from anthropogenic disturbance, receiving a dose of disturbance not typical of the entire wetland or vegetation zone, or it may have contained some "natural" chemical/physical component that was unique. Regardless of the cause, the area was not representative of the entire wetland. The influence of those outliers was dampened by using the median in place of mean as a measure of central tendency.

Continued Testing and Validation of IBI - We continued to collect data from sites of known anthropogenic disturbance and used these to check the calibration of our IBIs. We continued to test the model by collecting data from previously sampled sites as well as additional wetlands experiencing a range of anthropogenic disturbance. All of these data were used to search for new potential metrics while still providing the information necessary to establish baselines and begin to pinpoint wetlands, or even wetland functions, where restoration efforts should be focused.

Results

Lacustrine Invertebrate Data

IBI scores- We applied our modified IBI (modified from Uzarski et al. (submitted) to enable family-level macroinvertebrate identification) to macroinvertebrate data from twenty wetland sites. When the modified IBI scores were calculated using family level data, sites separated along a perceived gradient of anthropogenic disturbance. IBI scores ranged from 86.1% of the total points possible at the Cedarville site to 40.9% at the Bradleyville Rd. site. The four sites that scored highest fell into the 'mildly impacted' category, while nine fell into the 'moderately impacted' category. The remaining seven sites were categorized as 'moderately degraded'. Three of the four sites that scored in the 'mildly impacted' range were northern Lake Michigan sites (Rapid River, Garden Bay and Ogontz Bay). The remaining four northern Lake Michigan sites were shown to be more degraded with the Big Fishdam, Ludington Park and Pt. St. Ignace sites all falling into the 'moderately impacted' category and the Escanaba site falling into the 'moderately degraded' category. All northern Lake Huron sites, with the exception of Cedarville, fell into the 'moderately impacted' category. As expected, Saginaw Bay sites had the lowest IBI scores with six of the seven sites falling into the 'moderately degraded' category. The Jones Rd. site was among these six sites. Because Typha was the only vegetation zone found at the Jones Rd. site, and our Typha zone specific metrics are still being developed, we scored this site using the Inner *Scirpus* metrics. Therefore, the score for this site may not be an accurate reflection of its biotic integrity. Wigwam Bay was categorized as 'moderately impacted' placing it among the northern Lake Huron sites. This was expected *a priori* because Wigwam bay was located closest to the outer bay of Saginaw Bay where anthropogenic disturbances would be diluted. This site had a largely forested watershed and was located furthest from the mouth of the Saginaw River, a known source of pollution for Saginaw Bay. Table 2 shows IBI metric scores and site ranking based on the modified IBI for the 20 fringing wetland sites.

We used generic level invertebrate data from eight of these sites to calculate metrics and apply these to our unmodified IBI (u-IBI) (Uzarski et al. submitted) to determine the reliability of the modified IBI. The ranked order of sites produced by the u-IBI with data at the higher taxonomic resolution was identical to the order produced by the modified IBI using family-level macroinvertebrate data. Once again, the Cedarville site ranked highest, scoring 86.1% of the total points possible, while the Vanderbilt Park site ranked lowest at 46.7%. Three sites, Cedarville, Mackinaw Bay and Shepard Bay fell into the 'mildly impacted' category and Pt. St. Ignace and Wildfowl Bay fell into the 'moderately impacted' category. Allen Rd., Jones Rd. and Vanderbilt Park were placed into the 'moderately degraded' category. Again, the Jones Rd. site was scored using Inner *Scirpus* metrics, and therefore, may be misrepresented. Table 3 shows IBI metric scores and site ranking based on the unmodified IBI for these 8 fringing wetland sites.

Anthropogenic disturbance was characterized using analyses of 11 water chemical/physical parameters for each vegetation zone within each site. These were used in conjunction with five land-use/cover parameters calculated from a 1 km buffer around each site. Principal components analysis (PCA) of all 16 parameters was of little value in partitioning sites along a gradient of anthropogenic disturbance (Figure 2). However, PCA of the 11 water chemical/physical parameters alone revealed a gradient of anthropogenic disturbance evident by increasing Cl, SpC, NO_3 and SO_4 in PC 2 (which explained 23.6% of the variability in the data-set) (Figure 3). Chemical/physical parameters that could be perceived as indicators of anthropogenic disturbance did not contribute strongly to PC 1. Therefore, PC 2 scores were used to characterize water quality among wetland sites. The Jones Rd. site scored highest in PC 2 and had the highest SpC, Cl and SO_4 of the 20 sites. Saginaw Bay sites generally scored highest in PC 2 while sites of northern Lake Huron and northern Lake Michigan scored lowest.

Since the PCA was conducted on chemical/physical data from individual vegetation zones, within-wetland spatial variability could be ascertained from the analysis. In most cases vegetation zones of a given site plotted near one another. Wet meadow zones of the St. Ignace, Shepards Bay and Big Fishdam sites, however, had significantly higher PC 2 scores than their respective inner and outer *Scirpus* zones, suggesting pronounced spatial heterogeneity in terms of water quality.

PCA of five land-use/cover parameters separated sites in three directions based on agriculture/meadow/idle land, developed land/road density and forested land (Figure 4). The Allen Rd. and Vanderbilt Park sites were characterized by their high proportion of surrounding agriculture while the Jones Rd. and Ludington Park sites were characterized by their high proportion of surrounding developed land and high road density. Sites that had high proportions of surrounding forested land include Big Fishdam, Ogontz Bay and Moscoe Channel. Most sites could not be characterized as having an overwhelming proportion of a given land-use/cover type. Hence, anthropogenic disturbance could not be determined directly from the PCA of land-use/cover.

Pearson correlations between PC 2 scores of the chemical/physical data and IBI scores (% possible) were conducted to test both IBIs. A significant correlation ($p<0.05$, $r=-0.503$) existed between PC 2 scores and IBI scores of individual vegetation zones using the modified IBI with family-level macroinvertebrate data (Figure 5). A Pearson correlation was also conducted between IBI scores and the means of PC 2 scores for each site (integrating all vegetation zones). This correlation was also significant ($p<0.05$, $r=-0.622$)(Figure 6). Pearson correlations were also conducted for sites where lowest operational taxonomic unit data were available. The correlation was significant ($p<0.05$, $r=-0.599$) between u-IBI scores for individual vegetation zones and their corresponding PC 2 scores. The best correlation ($p<0.05$, $r=-0.93$) was found between mean PC 2 scores (means of all vegetation zones per site) and site u-IBI scores calculated using the lowest operation taxonomic unit dataset (Figure 7). The Jones Road site was excluded from this analysis. Significant correlations between PC 2 scores and IBI scores show that the IBI ranked sites based on anthropogenic disturbance. In this case PC 2 was composed primarily of Cl, SpC, NO_3 and SO_4. These parameters can be considered surrogates for anthropogenic disturbance or, more specifically, runoff from urban or agricultural areas. Both IBIs separated the more-impacted sites of Saginaw Bay from the reference sites of northern Lake Huron and northern Lake Michigan. However, the least impacted Saginaw Bay site because of its distance from the outlet of the Saginaw River and proximity to the outer bay, Wigwam Bay, scored among the northern sites. This distance allows for dilution of anthropogenic inputs entering Saginaw Bay. The Pinconning and Wildfowl Bay sites were also a significant distance from the outlet of the Saginaw River and located near the outer bay. Their respective IBI scores reflected better water quality. The PCA did not separate the Wigwam Bay, Wildfowl Bay and Pinconning sites from the other Saginaw Bay sites, suggesting that our chemical/physical data alone, did not have the resolution to account for a gradient of water quality within Saginaw Bay.

The Escanaba site had the lowest IBI score of any northern Lake Huron or Lake Michigan site. This low score was consistent with our belief that this wetland was impacted by the Escanaba river and the expansive urbanization and industry of Escanaba. The Ludington Park site was also in this region of Lake Michigan and hence, scored among the lowest three northern sites. The IBI score of the Ludington Park site may have been confounded by the morphology of the wetland. The *Scirpus* at this site was designated as 'Inner *Scirpus*' even though this site had a substantial fetch. It was designated as such because the *Scirpus* showed characteristics typical of this zone (very dense) and was protected by a barrier sand bar. However, it was noted that this bar was often submerged by seiche and/or storm activity. Thus, *Scirpus* grew in dense 'islands' unlike the vegetation zonation at any other site. The system was undoubtedly subject to occasional storm surges, but likely most often resembled a protected zone. This relatively unique setting makes this particular vegetation zone difficult to categorize. While this site is an example of how vegetation zones are not always discrete, the IBI still ranked the Ludington Park site as predicted by the chemical/physical analyses. Furthermore, recalculation of the IBI score for the Ludington Park site by considering the *Scirpus* islands as outer *Scirpus* did not change the ranked order of sites suggesting that the IBI is robust to such discrepancies.

The Jones Rd. site was the only site sampled that did not include either a *Scirpus* or wet meadow zone. Since our current IBI depends on these vegetation types (our Typha zone metrics are currently being reevaluated and improved), we could not accurately describe the Jones Rd. site. Applying Inner *Scirpus* metrics to the Jones Rd. Typha zone placed the site among the other moderately-degraded Saginaw Bay sites. The chemical/physical nature of the Jones Rd. site, as well as data from previous years, also suggested that the site is one of the most degraded sites sampled.

Both the u-IBI and the modified IBI, ranked the Cedarville site as the most pristine of the 20 wetlands. However, field observations, and studies over the past six years indicate that the Cedarville site is impacted by a number of anthropogenic inputs. The wetland is adjacent to the city of Cedarville, a busy boat channel, and receives treated sewage effluent twice per year. The sediment at the Cedarville site appeared heavily organic and the *Scirpus* community was mixed with dense duckweed (*Lemna sp.*) and lily (*Nurphar* sp.) mats. Analysis of the chemical/physical nature of the Cedarville site, however, did not reflect the perceived anthropogenic disturbance and was consistent with the IBI score.

Palustrine Invertebrate Data

We sampled invertebrates along with accompanying chemical/physical water quality parameters from 14 habitat zones within 10 depressional wetlands in the coastal zone of Lake Michigan. Initially, sites were considered to be in the "coastal zone" if their water levels were influenced by Great Lakes hydrology (via subsurface connection). However, we modified our site selection criteria to include more surface water-driven wetlands (where little subsurface connection to Lake Michigan was apparent based on chemical/physical data). These systems likely have more of a groundwater connection to the lake during higher water years. Inclusion of these sites during times of more surface than groundwater influence allowed us to explore the response of invertebrate community composition to chemical/physical condition of both hydrologic regimes. Palustrine sites were then considered to be in the "coastal zone" if they were within 1 km of the Lake Michigan Shore. Palustrine site locations are found in table 1 and figure 1b.

Preliminary analysis of invertebrate data for coastal zone depressional wetlands suggested that the community composition within these wetlands is highly variable across hydrologic regimes and habitat types. At a coarse taxonomic scale no particular taxa dominate the dataset (Figure 8). Hydrology appears to have an important effect on community composition within these depressional sites. The two wetlands with the highest genera richness (the Ludington State Park Service Road site and the Silver Lake State Park *Scirpus* site) were the only two sites that had an alkalinity high enough to suggest a significant groundwater source. The Ludington State Park Service Road site was approximately 20 meters from a limestone road that may have contributed to the site's alkalinity. However, upon visiting sites in the early spring we found that the Ludington State Park Service Road and the Silver Lake State Park *Scirpus* sites were inundated while the other sites in the area (Nordhouse Dunes, Ludington Cedar Trail, Silver Lake ORV, Muskegon State Park Swamp and Muskegon State Park Interdunal) were dry. These observations, along with the higher alkalinity, support our belief that the two sites with the highest generic diversity were more groundwater influenced than the others.

We conducted Pearson correlations between insect relative abundance, genera richness and alkalinity to explore the connection between hydrologic regime and community composition. A significant correlation ($p<0.05$) between genera richness and alkalinity suggested that sites receiving a significant amount of groundwater were more stable in their hydrologic and chemical/physical nature leading to a more complex invertebrate community structure. Alkalinity alone, however, may not adequately characterize the water source for these systems and a more intuitive approach may lend itself better to understanding the extent to which invertebrate community composition is dictated be hydrology. For instance, site visits in April of 2003 indicated that one-half of the vegetation zones sampled in 2002 did not contain standing water. These zones that were dry in 2003 tended to have higher %Insect and lower genera richness in 2002 when they were inundated than the 7 zones that were inundated both years. Genera richness between these two groups of sites was significantly different ($p<0.05$) while %Insects was not (Figures 9 and 10) suggesting that the insects are fast colonizers and can take advantage of a very short inundation period.

The ambient chemical/physical conditions of the 10 sites were highly variable. Much of this variability, as previously mentioned, was likely due to hydrology. A PCA was conducted on 12 chemical/physical parameters for the 14 habitats sampled (Figure 11). PC 1 of the analysis shows a gradient from surface water-driven sites on the left to groundwater driven sites on the right. Eigenvectors for conductivity, pH and alkalinity are plotted in the same direction and to the right. These parameters are most responsible for PC 1 and are pulling sites out in a gradient from surface water to groundwater-driven. In this analysis anthropogenic disturbance is difficult to determine due to the confounding factor of hydrology and wetland type.

Lacustrine Fish Data

We were able to include fish data from 61 sites spanning all five Great Lakes in our analyses (5 Superior, 18 Michigan, 13 Huron, 13 Erie, and 12 Ontario) by including the data collected by our collaborators, Joel Ingram and Steve Timmermans from Environment Canada and Bird Studies Canada respectively. All of the inundated vegetation zones were fished in each wetland providing us with 15,263 fish from seven different plant zones (104 observations after combining replicate plant zones within wetlands) with 260 total net-nights fished. Our objective of this portion of the project was to determine if fish community composition was being structured based on Great Lake (Superior, Michigan, Huron, Erie, and Ontario), ecoregion (eastern Lake Superior northern Lake Huron, Saginaw Bay Lake Huron, northern Lake Michigan, northeastern Lake Michigan, southeastern Lake Michigan, Long Point Lake Erie, western Lake Ontario, and eastern lake Ontario), wetland type (protected embayment, open lacustrine, barrier beach, and drowned river mouth), vegetation type (bulrush, spikerush, wild rice, lily, pickerel weed-arrowhead-arrow arum, burreed, and cattail), or chemistry and land use to determine the feasibility of developing an extremely valuable Great Lakes basin wide IBI using key fish taxa.

We included fish data and the accompanying SRP, NH_4, NO_2/NO_3, SO_4, Cl, DO, temperature, turbidity, sp. conductance, pH, alkalinity, Redox potential, and land use/cover data in our analyses. We ran PCA using only the abiotic data to first determine if our sites ordinated on any of the levels of interest (lake, ecoregion, wetland type, or vegetation zone). Results of these analyses (Figure 12) showed that vegetation zone was the single most important factor ordinating the sites based on these chemical/physical and adjacent land use data. The sites grouped into three major categories: 1) bulrush sites with low respiration and relatively high proportions of adjacent forests; 2) high nutrient and high percentage of adjacent agriculture cattail sites, and finally, 3) cattail sites with relatively high urbanization and urban runoff such as chloride.

We then performed correspondence analyses using the fish data to determine if those data alone grouped sites at any of our chosen levels (Lake, ecoregion, wetland type, or vegetation zone). Initially, rare taxa were removed from the data set leaving 42 species in the analyses. Bowfin and black bullhead overwhelmed the first and second dimensions of the analysis respectively. These taxa tend to school and our nets happened to catch large schools at several sites. We observed large schools of these taxa at most of our sites, and therefore, could justify removing them from our subsequent analyses since we could attribute these large catches at a portion of our sites to happenstance alone. We continued this process, documenting the taxa removed and the justification for removal until 26 species remained (Table 5). Our goal was to use these iterations to reduce the number of taxa to a group that could represent a community typical of coastal wetlands of all five Great Lakes, and therefore, evenly distribute the sites in two-dimensional space. This even distribution of sites could then reveal the underlying factor(s) responsible for characterizing fish community composition in Great Lakes coastal wetlands, and in turn establishing indicator taxa for these systems. The 26 species separated the sites based on vegetation zone similar to the PCA. Pearson correlation was then used to relate CA dimensions, or fish community composition, to PCs, or chemical/ physical and land use/cover data. A significant correlation ($r=0.398$, $p < 0.001$) existed between CA_1 and PC_1 establishing a relationship between fish community composition and chemistry and land use (Figure 13). We then super imposed our four levels as a third dimension over this relationship to discover that our chemistry and land use data were most closely related to vegetation zone (Figures 13).

In conclusion, vegetation zone was the most important variable structuring fish community composition, regardless of Lake, ecoregion, or wetland type. Vegetation zone was most likely determined by nutrient concentrations and adjacent land use /cover as well as fetch and pelagic mixing. Although, within these vegetation zones, fish community composition seemed to respond to nutrient concentrations and/or fetch and pelagic mixing. However, it should be noted that this could simply be correlative since fetch and pelagic mixing should contribute to plant zonation and the dilution of nutrients and/or the amount of organic sediment accumulation. We should also note that macroinvertebrates also respond to these variables (Burton et al., Uzarski et al. Burton et al.), and therefore, could also contribute to changes in fish community composition since they are often utilized as a food source. In general, fish communities tended to move from a ‘banded killifish, pugnose shiner, redear sunfish, smallmouth bass, whitemouth shiner, white sucker, and yellow perch community’ to a ‘brook silverside, brown bullhead, fathead minnow, golden shiner, green sunfish, and spotfin shiner community as nutrients and adjacent agriculture increases along an environmental gradient (Figure 14).

Acknowledgements

•Great Lakes National Program Office (GLNPO)
•Great Lakes Commission
•Michigan Department of Environmental Quality (MDEQ)
•Michigan Great Lakes Protection Fund
•Region V, U. S. Environmental Protection Agency (EPA)
•Ontario Ministry of Natural Resources, Peterborough District
•Mr. Beau Braymer
•Mr. Nathan Coady
•Mr. Kenneth Davenport
•Mr. John Genet
•Ms. Kelly Martin

•Mr. Shawn Wessell
•Mr. Alan Tepley

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Table Titles:

1. 2002 coastal wetland sampling sites

2. IBI metric scores for 20 Lake Michigan and Lake Huron lacustrine wetlands sampled in 2002. IBI scores are based on metrics modified from Uzarski et al. (submitted) to allow for family-level identification.

3. IBI scores for 8 coastal lacustrine sites with macroinvertebrate data at Lowest Operational Taxonomic Unit.

4. Abbreviations for 20 coastal lacustrine wetland sites

5. Fish Species list by ecoregion.

6. Total number of fish collected in 2002 in fyke nets from northern Lake Huron fringing wetlands.

7. Total number of fish collected in 2002 in fyke nets from Lake Superior fringing and riverine wetlands.

8. Total number of fish collected in 2002 in fyke nets from northern Lake Michigan coastal fringing wetlands.

9. Total number of fish collected in 2002 in fyke nets from Lake Michigan drowned river mouth wetlands (sites north of Muskegon).

10. Total number of fish collected in 2002 in fyke nets from Lake Michigan drowned river mouth wetlands (sites south of Muskegon).

11. Total number of fish collected in 2002 in fyke nets from Saginaw Bay coastal fringing wetlands.

Figure Titles:

1a. Map of 2002 wetland sampling locations.
1b. Map of 2002 coastal depressional wetland sampling sites

2. PCA of 16 chemical/physical and land-use/cover parameters for 20 fringing wetlands of Lakes Huron and Michigan.

3. PCA of 11 chemical/physical parameters for 20 fringing wetlands of Lakes Huron and Michigan.

4. PCA of 5 land-use/cover parameters for 20 fringing wetlands of Lakes Huron and

Michigan.

5. Correlation between PC 2 scores of the chemical/physical PCA and IBI scores for individual vegetation zones calculated with family-level data for 20 fringing wetlands of Lakes Huron and Michigan.

6. Correlation between mean PC 2 scores (per wetland site) of the chemical/physical PCA and IBI scores calculated with family-level data for 20 fringing wetlands of Lakes Huron and Michigan.

7. Correlation between mean PC 2 scores (per wetland site) of the chemical/physical PCA and IBI scores calculated with data at lowest operational taxonomic unit for 20 fringing wetlands of Lakes Huron and Michigan.

8. Relative abundances of macroinvertebrates for 10 coastal palustrine wetland sites (14 habitat zones) of the eastern shore of Lake Michigan. Relative abundances were calculated as means of 3 replicate samples.

9. Genera richness of macroinvertebrates for 10 coastal palustrine wetland sites (14 habitat zones) of the eastern shore of Lake Michigan (median genera richness of 3 replicate samples).

10. Percent Insects in macroinvertebrate samples for 10 coastal palustrine wetland sites (14 habitat zones) of the eastern shore of Lake Michigan.

11. PCA of 12 chemical/physical parameters for 10 coastal palustrine wetlands (14 habitat zones)of the easterm shore of Lake Michigan.

12. PCA of chemical/physical and land-use/cover parameters for 61 coastal wetland sites, spanning all five Great Lakes sampled in 2002.

13. Correlation between dimension 1 of the CA of fish taxa from 61 coastal wetlands and PC 1 of the PCA of chemical/physical and land-use/cover parameters.

Table 1. 2002 coastal wetland sampling sites.

Site Name	Date of Sampling	Position		Lake	Vegetation Zone[1]
Fringing Wetlands					
Hessel Bay	7/15/2002	N46.00548	W84.43411	Huron	OS, IS
Mismer Bay	7/15/2002	N46.00719	W84.46217	Huron	OS, IS
Mackinaw Bay	7/15/2002	N46.00174	W84.40915	Huron	OS, IS, WM
Moscoe Channel	7/16/2002	N45.99175	W84.31438	Huron	OS, IS
Hill Island	7/16/2002	N45.98199	W84.31723	Huron	OS, IS
Shepards Bay	7/16/2002	N45.98346	W84.36425	Huron	OS, IS, WM
Cedarville	7/17/2002	N45.99678	W84.36251	Huron	OS, IS, WM
Pt.St. Ignace	7/18/2002	N45.84523	W84.73923	Michigan	OS, IS
Tahquamenon River	7/17/2002	N46.56088	W85.03021	Superior	N, S, T
Portage River	7/29/2002	N46.98710	W88.43303	Superior	S, P, SP, WM
Baraga State Park	7/30/2002	N46.75373	W88.49267	Superior	N
Ojibwa Bay	7/30/2002	N46.78597	W88.46542	Superior	E, WM, Z
Lightfoot Bay	7/30/2002	N46.89640	W88.20306	Superior	E, J
Escanaba	7/31/2002	N45.81790	W87.05235	Michigan	OS, IS
Ludington Park	7/31/2002	N45.73874	W87.05646	Michigan	OS
Ogontz Bay	7/31/2002	N45.83229	W86.78177	Michigan	OS, IS
Rapid River	7/31/2002	N45.9137	W86.96622	Michigan	OS, IS, T
Garden Bay	8/2/2002	N45.99678	W86.57316	Michigan	OS, IS
Big Fishdam	8/2/2002	N45.89271	W86.58555	Michigan	OS, IS, J
Wigwam Bay	8/20/2002	N43.96345	W83.8569	Huron	IS, OS, J
Pinconning	8/21/2002	N43.85401	W83.9153	Huron	IS, OS
Vanderbilt Park	8/21/2002	N43.60082	W83.66103	Huron	IS, OS
Wildfowl Bay	8/22/2002	N43.80198	W83.4628	Huron	IS
Allen Rd.	8/22/2002	N43.64172	W83.6092	Huron	T, S
Jones Rd.	8/23/2002	N43.64235	W83.81427	Huron	T
Bradleyville Rd.	8/29/2002	N43.621203	W83.63474	Huron	IS, OS
Drowned Rivermouths					
Arcadia River	6/27/2002	N44.48858	W86.23041	Michigan	N, SP, T
Lincoln River	7/1/2002	N43.98137	W86.43391	Michigan	S, SP, N, T
Pere Marquette River	7/2/2002	N43.92949	W86.40756	Michigan	Y, T, P, SP
Pentwater River	6/28/2002	N43.76023	W86.40048	Michigan	N, T, SP, S
White River	7/8/2002	N43.41315	W86.34661	Michigan	Y, SP, N, T
Muskegon River	6/13/2002	N43.26593	W86.23341	Michigan	N, T, P
Little Black Creek	6/26/2002	N43.18610	W86.24681	Michigan	T
Norris Creek	6/24/2002	N43.12100	W86.15175	Michigan	N
Grand-Bruces Bayou	6/24/2002	N43.04746	W86.10401	Michigan	N, PE, Y, T
Little Pigeon River	6/17/2002	N42.96297	W86.21807	Michigan	N, P
Pigeon River	6/17/2002	N42.90603	W86.17923	Michigan	T, SP, N

Table 1. Continued

Site Name	Date of Sampling	Position		Lake	Vegetation Zone[1]
Depressional Wetlands					
Nordhouse Dunes Marsh	6/3/2002	N44.12336	W86.37273	Michigan	GR
Nordhouse Dunes Swamp	6/3/2002	N44.12336	W86.37273	Michigan	LL
Ludington SP Service Road	6/4/2002	N44.03940	W86.50900	Michigan	CA
Ludington SP Cedar Trail Marsh	6/4/2002	N44.02468	W86.49131	Michigan	T/S
Silver Lake SP Scirpus	6/5/2002	N43.64880	W86.53108	Michigan	S/E
Silver Lake SP ORV Area Marsh	6/5/2002	N43.68803	W86.51283	Michigan	T
Silver Lake SP ORV Area Marsh	6/6/2002	N43.68758	W86.51300	Michigan	S
Muskegon SP Interdunal Marsh	5/30/2002	N43.23616	W86.33341	Michigan	J
Muskegon SP Lost Lake	5/30/2002	N43.25431	W86.34198	Michigan	Y, CA
Muskegon SP Swamp	5/31/2002	N43.25458	W86.34158	Michigan	MS
Saugatuck Dunes SP Swamp	6/10/2002	N42.70286	W86.19660	Michigan	PO, MS
Van Burren SP Swamp	6/10/2002	N42.33975	W86.30038	Michigan	W

[1] Vegetationa Zones: OS, Outer Scirpus; IS, Inner Scirpus; WM, Wet Meadow; N, Nuphar; S, Scirpus; T, Typha; P, Pontederia; SP, Sparganium; E, Eleocharis; Z, Zizania; J, Juncus, Y, Nymphaea; PE, Peltandra; GR, Mixed Gras LL, Leather Leaf; CA, Carex; MS, Mixed Shrub; PO, Potamogeton; W, Willow

Table 2. IBI Metric Scores for 20 Lake Michigan and Lake Huron lacustrine wetlands sampled in 2002
(IBI scores are based on metrics modified from Uzarski et al. to allow for family-level macroinvertebrate data.

Site	Veg. Zone	Odanata TR	Odanata %RA	Crust.+Mull. TR	Family TR	Gastropoda %RA	Sphearidae %RA	Ephem.+Trich TR	Crust.+Mull. %RA	Isopoda %RA
Cedarville	Inner Scirpus	5	5	7	7	7	5	1	5	7
Rapid River	Outer Scirpus	5	7	7	12	7	1		5	
	Inner Scirpus	5	5	7	7	7	1	3	5	3
	Wet Meadow	3	5	3	5	3	1			
Garden Bay	Outer Scirpus	1	1	7	8	7	1		5	
	Inner Scirpus	5	7	5	7	7	1	3	5	7
Ogontz Bay	Outer Scirpus	5	7	3	6	7	1		5	
	Inner Scirpus	5	7	5	7	7	5	3	3	3
Hessel Bay	Outer Scirpus		5	7	10	7	1		5	
	Inner Scirpus	5	5	5	7	7	1	3	5	1
Mackinaw Bay	Outer Scirpus	5	5	7	10	7	1		5	
	Inner Scirpus	5	5	5	7	7	1	3	5	0
	Wet Meadow	3	3	3	3	5	1			
Moscoe Channel	Outer Scirpus	5	3	3	6	7	1		3	
	Inner Scirpus	5	7	5	7	7	1	3	5	5
Hill Island	Outer Scirpus	5	5	5	6	7	1		5	
	Inner Scirpus	5	5	7	5	7	1	3	5	3

Table 2. Cont.

Site	Veg. Zone	Odanata TR	Odanata %RA	Crust.+Mull. TR	Family TR	Gastropoda %RA	Sphearidae %RA	Ephem.+Trich TR	Crust.+Mull. %RA	Isopoda %RA
Wigwam Bay	Outer Scirpus	5	7	3	10	5	1		5	
	Inner Scirpus	5	5	3	3	5	1	3	5	0
	Wet Meadow	3	5	3	3	3	1			
Shepard Island	Outer Scirpus	1	1		10	7	1		5	
	Inner Scirpus	5	5	7	7	7	5	3	5	3
	Wet Meadow	3	3	3	3	5	1			
Big Fishdam	Outer Scirpus	1	1	3	6	7	5		3	
	Inner Scirpus	5	3	5	5	7	5	3	5	0
	Wet Meadow	3	3	3	3	5	1			
Ludington Park	As Inner	7	7	1	10	7	1		3	
	As Outer	7	7	1	5	7	1	3	3	0
Pt.St. Ignace	Outer Scirpus	1	1	5	6	7	5		5	
	Inner Scirpus	5	3	5	3	7	1	3	3	0
Pinnconning	Outer Scirpus	1	1	3	6	5	1		5	
	Inner Scirpus	5	7	3	5	5	1	3	3	0
Wildfowl Bay	Inner Scirpus	5	7	3	3	3	1	3	3	0
Escanaba	Outer Scirpus	1	1	3	6	1			1	
	Inner Scirpus	5	7	5	3	7	5	3	5	0
Allen Rd	Inner Scirpus	5	7	1	3	1	1	3	1	0

Table 2. Cont.

Site	Veg. Zone	Odanata TR	Odanata %RA	Crust.+Mull. TR	Family TR	Gastropoda %RA	Sphearidae %RA	Ephem.+Trich TR	Crust.+Mull. %RA	Isopoda %RA
Jones Rd	Typha (calculated as Inner Scirpus)	5	7	1	3	1	1	3	5	0
Vanderbuilt Park	Outer Scirpus	1	1	3	6	3	1		3	
	Inner Scirpus	3	3	5	5	7	1	3	3	0
Bradleyville Rd	Outer Scirpus	1	1	1	6	1	1		3	
	Inner Scirpus	5	3	3	3	1	1	3	3	0

Table 2. Cont.

Site	Veg. Zone	Shannon Diversity	Evenness	Simpson Diversity	Total IBI Score	IBI Class	Total Possible	%total
Cedarville	Inner Scirpus	5	5	3	62	Mildly Impacted	72	86.11
Rapid River	Outer Scirpus	5	5	5	59			
	Inner Scirpus	5	5	5	58			
	Wet Meadow	5	5	5	35			
					152	Mildly Impacted	182	83.52
Garden Bay	Outer Scirpus	5	5	5	45			
	Inner Scirpus	5	5	3	60			
					105	Mildly Impacted	137	76.64
Ogontz Bay	Outer Scirpus	3	5	3	45			
	Inner Scirpus	5	5	5	60			
					105	Mildly Impacted	137	76.64
Hessel Bay	Outer Scirpus	5	5	3	48			
	Inner Scirpus	5	5	5	54			
					102	Moderately Impacted	137	74.45
Mackinaw Bay	Outer Scirpus	3	5	3	51			
	Inner Scirpus	5	5	5	53			
	Wet Meadow	3	5	3	29			
					133	Moderately Impacted	182	73.08
Moscoe Channel	Outer Scirpus	3	5	3	39			
	Inner Scirpus	5	5	5	60			
					99	Moderately Impacted	137	72.26
Hill Island	Outer Scirpus	3	5	3	45			
	Inner Scirpus	5	5	3	54			
					99	Moderately Impacted	137	72.26

Table 2. Cont.

Site	Veg. Zone	Shannon Diversity	Evenness	Simpson Diversity	Total IBI Score	IBI Class	Total Possible	%total	
Wigwam Bay	Outer Scirpus	5	5	5	51				
	Inner Scirpus	5	5	5	45				
	Wet Meadow	5	5	5	33				
					129	Moderately Impacted	182	70.88	
Shepard Island	Outer Scirpus	5	5	5	40				
	Inner Scirpus	5	5	3	60				
	Wet Meadow	3	3	3	27				
					127	Moderately Impacted	182	69.78	
Big Fishdam	Outer Scirpus	3	3	3	35				
	Inner Scirpus	5	5	5	53				
	Wet Meadow	5	5	5	33				
					121	Moderately Impacted	182	66.48	
Ludington Park	As Inner	3	3	3	45	Moderately Impacted	72	62.50	"Inner Scirpus"
	As Outer	3	3	3	43	Moderately Impacted	65	66.15	"Outer Scirpus"
Pt.St. Ignace	Outer Scirpus	3	5	3	41				
	Inner Scirpus	5	5	3	43				
					84	Moderately Impacted	137	61.31	
Pinnconning	Outer Scirpus	3	5	3	33				
	Inner Scirpus	5	5	3	45				
					78	Moderately Degraded	137	56.93	
Wildfowl Bay	Inner Scirpus	3	5	3	39	Moderately Degraded	72	54.17	
Escanaba	Outer Scirpus	3	3	1	20				
	Inner Scirpus	5	5	5	55				
					75	Moderately Degraded	137	54.74	
Allen Rd	Inner Scirpus	5	5	5	37	Moderately Degraded	72	51.39	

Table 2. Cont.

Site	Veg. Zone	Shannon Diversity	Evenness	Simpson Diversity	Total IBI Score	IBI Class	Total Possible	%total
Jones Rd	Typha	3	5	3	37	Moderately Degraded	72	51.39
	(calculated as Inner Scirpus)							
Vanderbuilt Park	Outer Scirpus	3	5	3	29			
	Inner Scirpus	3	3	1	37			
					66	Moderately Degraded	137	48.18
Bradleyville Rd	Outer Scirpus	3	3	1	21			
	Inner Scirpus	3	5	5	35			
					56	Moderately Degraded	137	40.88

Table 3. IBI metric values for 8 coastal wetland sites in order of decreasing IBI %score (metrics for invertebrate data at lowest operational taxonomic unit)

Site	Zone	Odanata TR	Odanata %RA	Crust.+Mull TR	Genera TR	Gastropoda %RA	Spaeridae %RA	Crust.+Mull. %RA	Ephem.+Trich. TR	Isopoda %RA
Cedarville	Inner Scirpus	2	2.70	8	20	27.42	1.35	79.03	0	39.52
Mackinaw Bay	Outer Scirpus	2	1.18	7	17	17.51	0.00	59.68	4	0.00
	Inner Scirpus	2	4.86	7	29	23.61	0.00	50.82	3	0.00
	Wet Meadow	2	2.26	5	23	57.14	0.00	69.17	1	0.00
Shepard Island	Outer Scirpus	0	0.00	5	19	10.81	0.00	43.24	3	3.57
	Inner Scirpus	2	2.06	8	20	19.21	6.19	64.79	1	1.03
	Wet Meadow	2	1.64	6	20	62.03	0.00	83.54	0	2.03
Pt.St. Ignace	Outer Scirpus	0	0.00	7	20	11.48	1.64	34.43	4	0.00
	Inner Scirpus	1	1.35	6	16	5.84	0.00	25.97	4	0.00
Wildfowl Bay	Inner Scirpus	2	12.12	3	14	0.55	0.00	26.47	2	0.00
Allen Rd	Inner Scirpus	3	19.21	2	18	0.00	0.00	5.96	3	0.00
Jones Rd	Typha (calculated as Inner Scirpus)	1	8.67	2	13	0.00	0.00	35.33	2	0.00
Vanderbilt Park	Outer Scirpus	0	0.00	4	11	1.54	0.00	12.12	2	0.00
	Inner Scirpus	1	1.10	3	14	9.94	0.00	14.36	3	0.00

Table 3. Cont.

Site	Zone	Family TR	Evenness	Shannon Diversity	Simpson Diversity	IBI Score		Total Possible	%Total
Cedarville	Inner Scirpus	20	0.76	0.99	0.18	62	Mildly Impacted	72	86.11
Mackinaw Bay	Outer Scirpus	14	0.73	0.91	0.18	53			
	Inner Scirpus	23	0.80	1.15	0.12	55			
	Wet Meadow	18	0.69	0.94	0.20	31			
						139	Mildly Impacted	182	76.37
Shepard Island	Outer Scirpus	16	0.90	1.17	0.07	47			
	Inner Scirpus	19	0.74	0.97	0.16	60			
	Wet Meadow	17	0.61	0.76	0.29	29			
						136	Mildly Impacted	182	74.73
Pt.St. Ignace	Outer Scirpus	13	0.85	1.05	0.12	53			
	Inner Scirpus	14	0.83	1.05	0.10	49			
						102	Moderately Impacted	137	74.45
Wildfowl Bay	Inner Scirpus	12	0.79	0.90	0.15	45	Moderately Impacted	72	62.50
Allen Rd	Inner Scirpus	14	0.80	0.98	0.13	41	Moderately Degraded	72	56.94
Jones Rd	Typha	12		0.84	0.18	37	Moderately Degraded	72	51.39
	(calculated as Inner Scirpus)		0.78						
Vanderbilt Park	Outer Scirpus	10	0.77	0.81	0.18	29			
	Inner Scirpus	13	0.56	0.64	0.34	35			
						64	Degraded	137	46.72

Table 4. Abbreviations for 20 coastal lacustrine wetland sites.

Site Name:	**Abbreviation:**	**Region:**
Hessel Bay	HB	N. Lk. Huron
Mackinac Bay	MB	N. Lk. Huron
Cedarville	C	N. Lk. Huron
Moscoe Channel	MC	N. Lk. Huron
Hill Island	HI	N. Lk. Huron
Shephards Bay	SB	N. Lk. Huron
St. Ignace	SI	N. Lk. Michigan
Escanaba	E	N. Lk. Michigan
Ludington Park	LP	N. Lk. Michigan
Rapid River	RR	N. Lk. Michigan
Ogontz Bay	OB	N. Lk. Michigan
Garden Bay	GB	N. Lk. Michigan
Big Fishdam	BF	N. Lk. Michigan
Wigwam Bay	WB	Saginaw Bay
Pinconning	P	Saginaw Bay
Vanderbilt Park	VP	Saginaw Bay
Wildfowl Bay	WF	Saginaw Bay
Allen Rd.	AR	Saginaw Bay
Jones Rd.	JR	Saginaw Bay
Bradleyvile Rd.	BR	Saginaw Bay

Vegetation Zone:	**Abbreviation:**
Wet Meadow	WM
Inner *Scirpus*	IS
Outer *Scirpus*	OS

Table 5. Fish Species list by ecoregion. Taxa maintained in correspondence analysis are denoted by *.

	Northern Lake Huron			**Saginaw Bay**	
	Common	**Scientific**		**Common**	**Scientific**
				Bowfin	Amia calva
	Alewife	Alosa pseudoharengus		Alewife	Alosa pseudoharengus
				Gizzard Shad	Dorosoma cepedianum
*	Spottail shiner	Notropis hudsonius		Spottail shiner	Notropis hudsonius
	Common shiner	Luxilis cornutus		Common shiner	Luxilis cornutus
	Blacknose shiner	Notropis heterolepis		Blacknose shiner	Notropis heterolepis
	Emerald shiner	Notropis atherinoides		Emerald shiner	Notropis atherinoides
*	Pugnose shiner	Notropis anogenus	*	Pugnose shiner	Notropis anogenus
*	Bluntnose minnow	Pimephales notatus			
	Silver chub	Macrhybopsis storeriana			
*	Common carp	Cyprinus carpio	*	Common carp	Cyprinus carpio
				Black redhorse	Moxostoma duquesnei
*	White sucker	Catostomus commersoni			
*	Banded killifish	Fundulus diaphanus	*	Banded killifish	Fundulus diaphanus
				Channel catfish	Ictalurus punctatus
	Black bullhead	Ameiurus melas			
*	Brown bullhead	Ameiurus nebulosus			
			*	Longnose gar	Lepisosteus osseus
*	Northern pike	Esox lucius			
	Ninespine stickelback	Pungitius pungitius			
*	Largemouth bass	Micropterus salmoides	*	Largemouth bass	Micropterus salmoides
*	Smallmouth bass	Micropterus dolomieu			
*	Rock bass	Ambloplites rupestris	*	Rock bass	Ambloplites rupestris
*	Bluegill	Lepomis macrochirus	*	Bluegill	Lepomis macrochirus

Table 5. Cont.

Northern Lake Huron		**Saginaw Bay**	
Common	**Scientific**	**Common**	**Scientific**
		White Crappie	Pomoxis annularis
* Pumpkinseed	Lepomis gibbosus	* Pumpkinseed	Lepomis gibbosus
		* Green sunfish	Lepomis cyanellus
* Redear sunfish	Lepomis microlophus		
		White perch	Morone americana
Johnny darter	Etheostoma nigrum	Johnny darter	Etheostoma nigrum
* Yellow Perch	Perca flavescens	* Yellow Perch	Perca flavescens
		Round goby	Neogobius melanostomus
		* Brook silverside	Labidesthes sicculus
		* Freshwater drum	Aplodinotus grunniens

Table 5. Cont.

	Northern Lake Michigan			Northeast Lake Michigan	
	Common	**Scientific**		**Common**	**Scientific**
	Bowfin	Amia calva		Bowfin	Amia calva
	Alewife	Alosa pseudoharengus			
	Gizzard Shad	Dorosoma cepedianum			
	Spottail shiner	Notropis hudsonius		Spottail shiner	Notropis hudsonius
				Spotfin shiner	Cyprinella spiloptera
	Common shiner	Luxilis cornutus		Common shiner	Luxilis cornutus
	Emerald shiner	Notropis atherinoides			
*	Pugnose shiner	Notropis anogenus			
*	Bluntnose minnow	Pimephales notatus			
*	Common carp	Cyprinus carpio	*	Common carp	Cyprinus carpio
				River redhorse	Moxostoma carinatum
*	White sucker	Catostomus commersoni	*	White sucker	Catostomus commersoni
*	Banded killifish	Fundulus diaphanus	*	Banded killifish	Fundulus diaphanus
	Black bullhead	Ameiurus melas		Black bullhead	Ameiurus melas
	yellow bullhead	Ameiurus natalis			
*	Longnose gar	Lepisosteus osseus			
*	Northern pike	Esox lucius			
				Grass pickerel	Esox americanus vermiculatus
*	Largemouth bass	Micropterus salmoides	*	Largemouth bass	Micropterus salmoides
*	Smallmouth bass	Micropterus dolomieu			
*	Rock bass	Ambloplites rupestris	*	Rock bass	Ambloplites rupestris
*	Bluegill	Lepomis macrochirus	*	Bluegill	Lepomis macrochirus

Table 5. Cont.

	Northern Lake Michigan			Northeast Lake Michigan	
	Common	**Scientific**		**Common**	**Scientific**
*	Black crappie	Pomoxis nigromaculatus			
*	Pumpkinseed	Lepomis gibbosus	*	Pumpkinseed	Lepomis gibbosus
			*	Green sunfish	Lepomis cyanellus
*	Redear sunfish	Lepomis microlophus	*	Redear sunfish	Lepomis microlophus
	Johnny darter	Etheostoma nigrum		Johnny darter	Etheostoma nigrum
*	Yellow Perch	Perca flavescens			
*	Central Mudminnow	Umbra limi			
	Round goby	Neogobius melanostomus			
	Burbot	Lota lota			

Table 5. Cont.

	Southeast Lake Michigan			Western Lake Superior	
	Common	**Scientific**		**Common**	**Scientific**
	Bowfin	Amia calva			
	Spottail shiner	Notropis hudsonius		Spottail shiner	Notropis hudsonius
	Spotfin shiner	Cyprinella spiloptera			
	Common shiner	Luxilis cornutus		Common shiner	Luxilis cornutus
				Blacknose shiner	Notropis heterolepis
	Blackspot shiner	????			
	Emerald shiner	Notropis atherinoides		Emerald shiner	Notropis atherinoides
			*	Pugnose shiner	Notropis anogenus
*	Bluntnose minnow	Pimephales notatus	*	Bluntnose minnow	Pimephales notatus
				Creek chub	Semotilus atromaculatus
			*	Common carp	Cyprinus carpio
	Quillback	Carpiodes cyprinus			
	River redhorse	Moxostoma carinatum		River redhorse	Moxostoma carinatum
*	White sucker	Catostomus commersoni			
*	Banded killifish	Fundulus diaphanus			
	Channel catfish	Ictalurus punctatus			
				Black bullhead	Ameiurus melas
*	Brown bullhead	Ameiurus nebulosus	*	Brown bullhead	Ameiurus nebulosus
*	Tadpole madtom	Noturus gyrinus			
*	Northern pike	Esox lucius			
	Grass pickerel	Esox americanus vermiculatus		Grass pickerel	Esox americanus vermiculatus
				Ninespine stickelback	Pungitius pungitius
*	Largemouth bass	Micropterus salmoides			
			*	Smallmouth bass	Micropterus dolomieu
*	Rock bass	Ambloplites rupestris	*	Rock bass	Ambloplites rupestris
*	Bluegill	Lepomis macrochirus	*	Bluegill	Lepomis macrochirus

Table 5. Cont.

Southeast Lake Michigan			Western Lake Superior		
	Common	Scientific		Common	Scientific
*	Pumpkinseed	Lepomis gibbosus			
*	Green sunfish	Lepomis cyanellus			
*	Redear sunfish	Lepomis microlophus			
				Johnny darter	Etheostoma nigrum
			*	Yellow Perch	Perca flavescens
*	Central Mudminnow	Umbra limi			
	Round goby	Neogobius melanostomus			

Table 5. Cont.

	Eastern Lake Superior			Long Point (Lake Erie)	
	Common	**Scientific**		**Common**	**Scientific**
				Bowfin	Amia calva
				Gizzard Shad	Dorosoma cepedianum
				Spotfin shiner	Cyprinella spiloptera
				Common shiner	Luxilis cornutus
			*	Blackchin shiner	Notropis heterodon
	Emerald shiner	Notropis atherinoides		Emerald shiner	Notropis atherinoides
*	Pugnose shiner	Notropis anogenus			
			*	Golden shiner	Notemigonus crysoleucas
			*	Bluntnose minnow	Pimephales notatus
				Hornyhead Chub	Nocomis biguttatus
			*	Common carp	Cyprinus carpio
			*	Banded killifish	Fundulus diaphanus
			*	Brown bullhead	Ameiurus nebulosus
			*	Tadpole madtom	Noturus gyrinus
			*	Longnose gar	Lepisosteus osseus
			*	Northern pike	Esox lucius
			*	Largemouth bass	Micropterus salmoides
			*	Smallmouth bass	Micropterus dolomieu
*	Rock bass	Ambloplites rupestris	*	Rock bass	Ambloplites rupestris
*	Bluegill	Lepomis macrochirus	*	Bluegill	Lepomis macrochirus

Table 5. Cont.

	Eastern Lake Superior			Long Point (Lake Erie)	
	Common	**Scientific**		**Common**	**Scientific**
			*	Pumpkinseed	Lepomis gibbosus
			*	Green sunfish	Lepomis cyanellus
	Iowa darter	Etheostoma exile			
*	Yellow Perch	Perca flavescens	*	Yellow Perch	Perca flavescens
				Round goby	Neogobius melanostomus
			*	Brook silverside	Labidesthes sicculus

Table 5. Cont.

	Western Lake Ontario			Eastern Lake Ontario	
	Common	**Scientific**		**Common**	**Scientific**
	Bowfin	Amia calva		Bowfin	Amia calva
	Alewife	Alosa pseudoharengus		Alewife	Alosa pseudoharengus
	Gizzard Shad	Dorosoma cepedianum			
	Spottail shiner	Notropis hudsonius		Spottail shiner	Notropis hudsonius
	Spotfin shiner	Cyprinella spiloptera		Spotfin shiner	Cyprinella spiloptera
	Common shiner	Luxilis cornutus			
				Blacknose shiner	Notropis heterolepis
			*	Blackchin shiner	Notropis heterodon
*	Fathead minnow	Pimephales promelas	*	Fathead minnow	Pimephales promelas
*	Golden shiner	Notemigonus crysoleucas	*	Golden shiner	Notemigonus crysoleucas
*	Bluntnose minnow	Pimephales notatus	*	Bluntnose minnow	Pimephales notatus
*	Common carp	Cyprinus carpio			
			*	White sucker	Catostomus commersoni
			*	Banded killifish	Fundulus diaphanus
*	Brown bullhead	Ameiurus nebulosus	*	Brown bullhead	Ameiurus nebulosus
	yellow bullhead	Ameiurus natalis			
			*	Tadpole madtom	Noturus gyrinus
			*	Northern pike	Esox lucius
				Threespine stickleback	Gasterosteus aculeatus
*	Largemouth bass	Micropterus salmoides	*	Largemouth bass	Micropterus salmoides
*	Rock bass	Ambloplites rupestris	*	Rock bass	Ambloplites rupestris
*	Bluegill	Lepomis macrochirus	*	Bluegill	Lepomis macrochirus

Table 5. Cont.

	Western Lake Ontario			Eastern Lake Ontario	
	Common	**Scientific**		**Common**	**Scientific**
*	Black crappie	Pomoxis nigromaculatus	*	Black crappie	Pomoxis nigromaculatus
*	Pumpkinseed	Lepomis gibbosus	*	Pumpkinseed	Lepomis gibbosus
			*	Redear sunfish	Lepomis microlophus
				White perch	Morone americana
*	Yellow Perch	Perca flavescens	*	Yellow Perch	Perca flavescens
				Logperch	Percina caprodes
			*	Central Mudminnow	Umbra limi

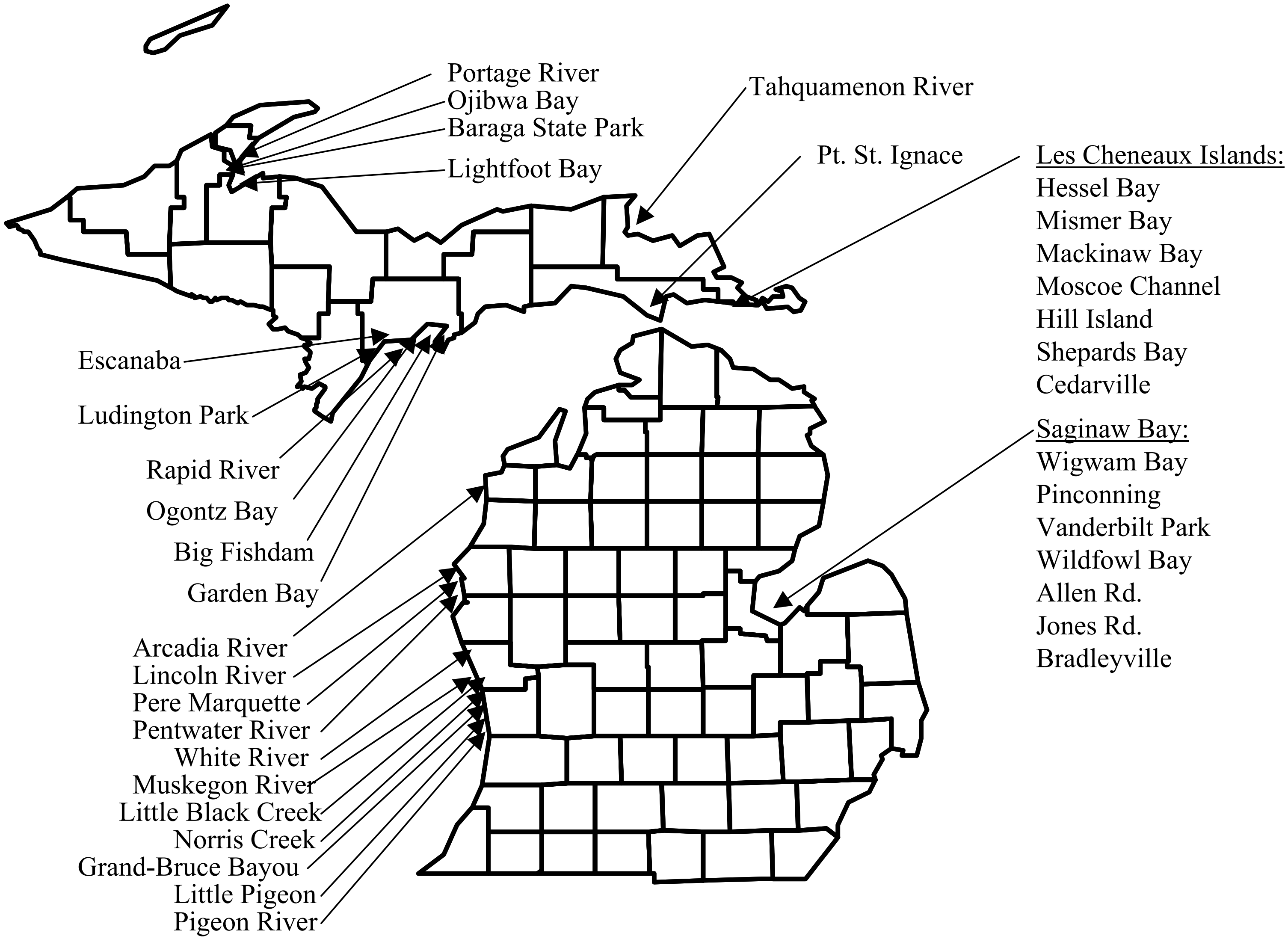

Figure 1a. 2002 Great Lakes lacustrine wetland sampling sites.

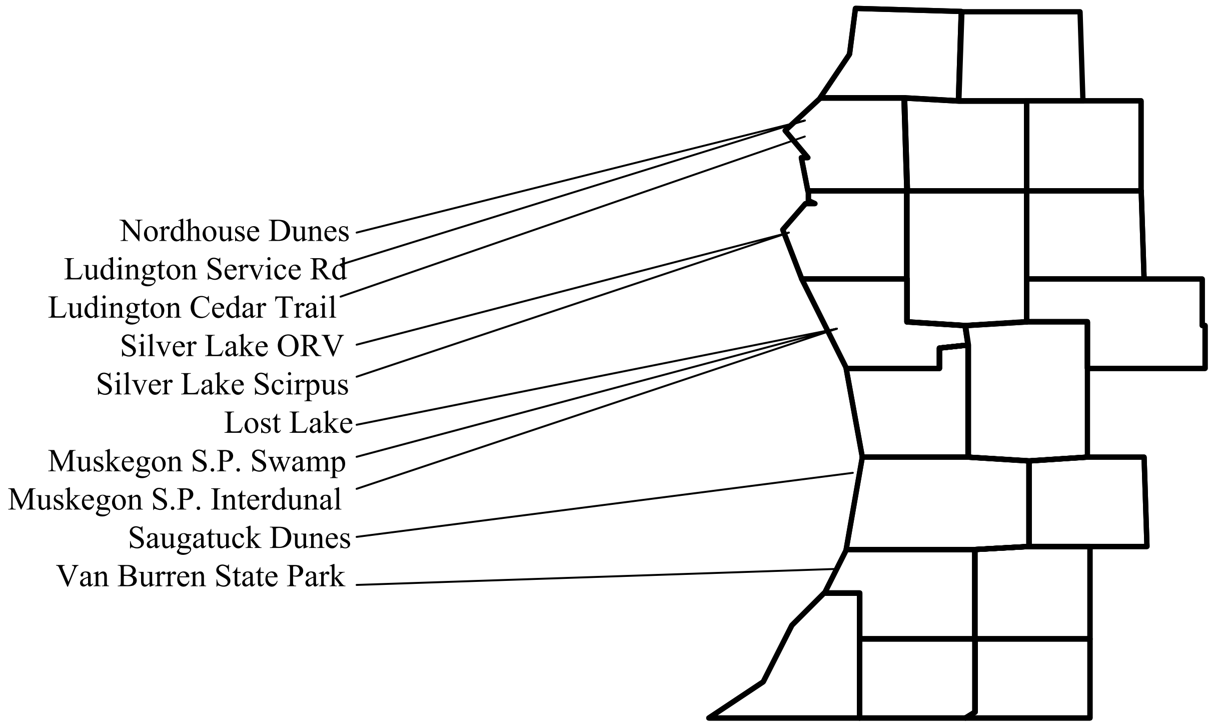

Figure 1b. 2002 coastal depressional wetland sampling sites.

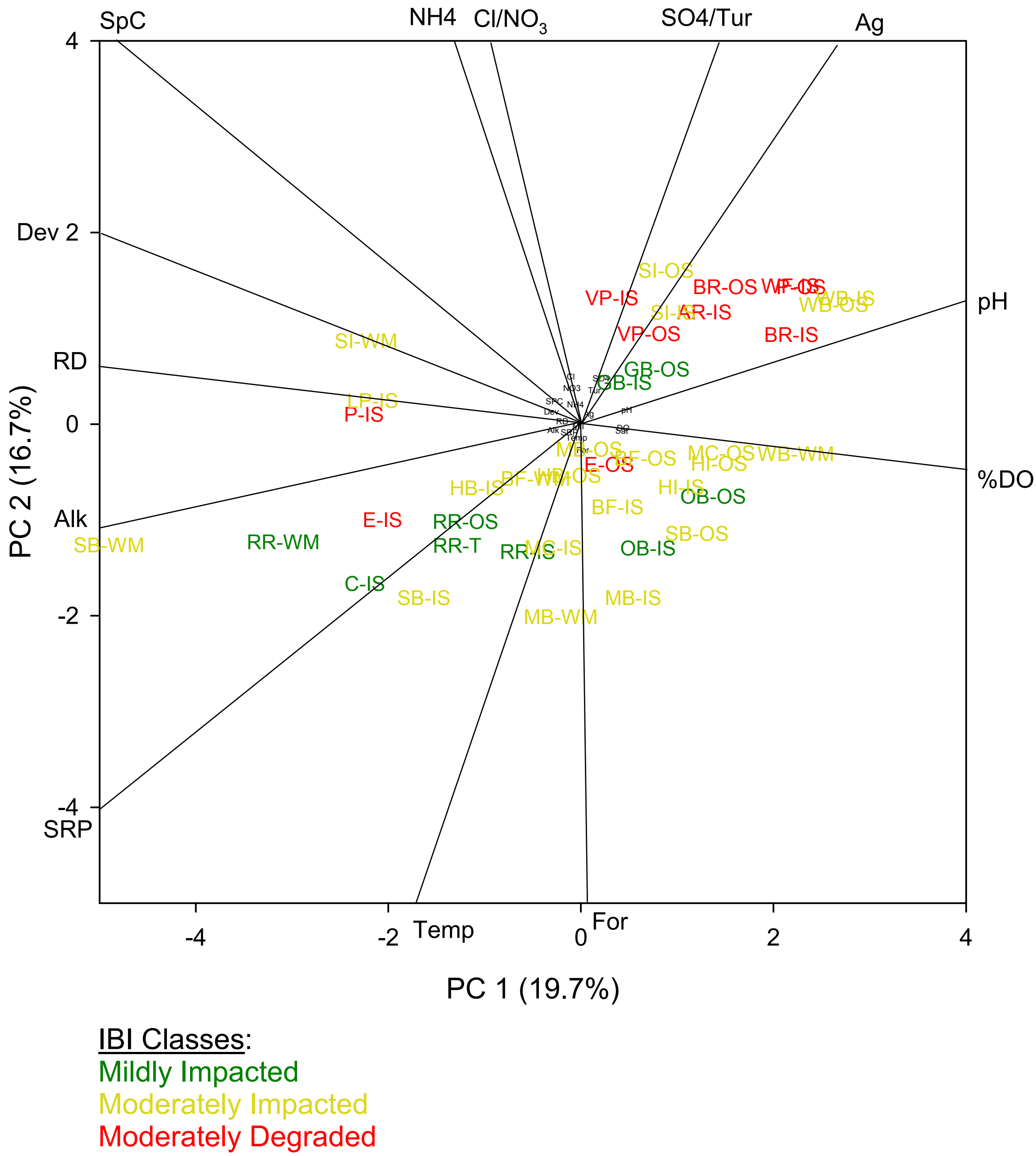

Figure 2. PCA of 20 coastal wetland sites of Lakes Michigan and Huron using 17 chemical/physical and land-use variables (Jones Rd is not show because it lies outside of plot area). See table 4 for site abreviations.

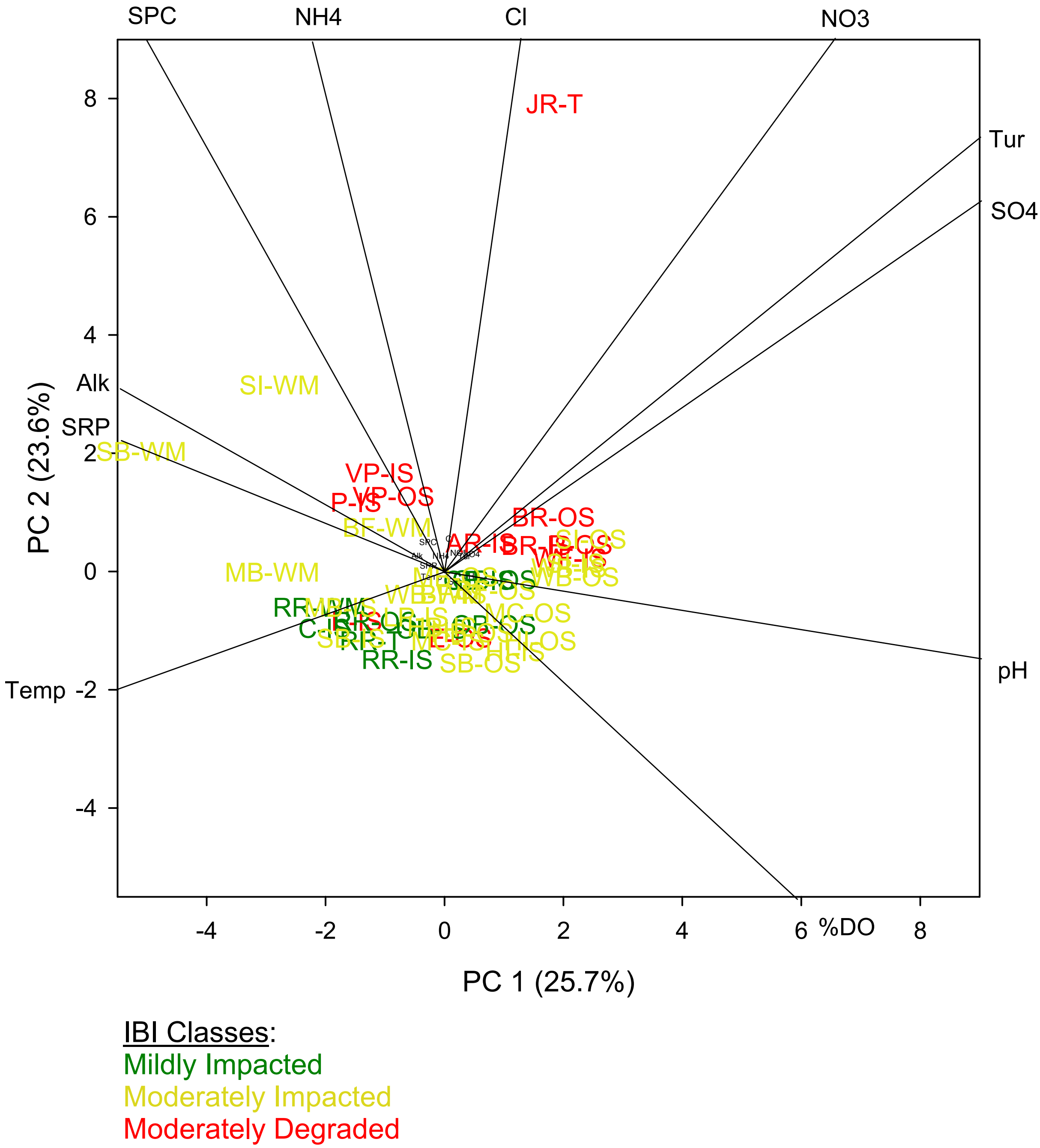

Figure 3. PCA of 20 coastal wetland sites of Lakes Michigan and Huron using 11chemical/physical variables. See table 4 for site abbreviations.

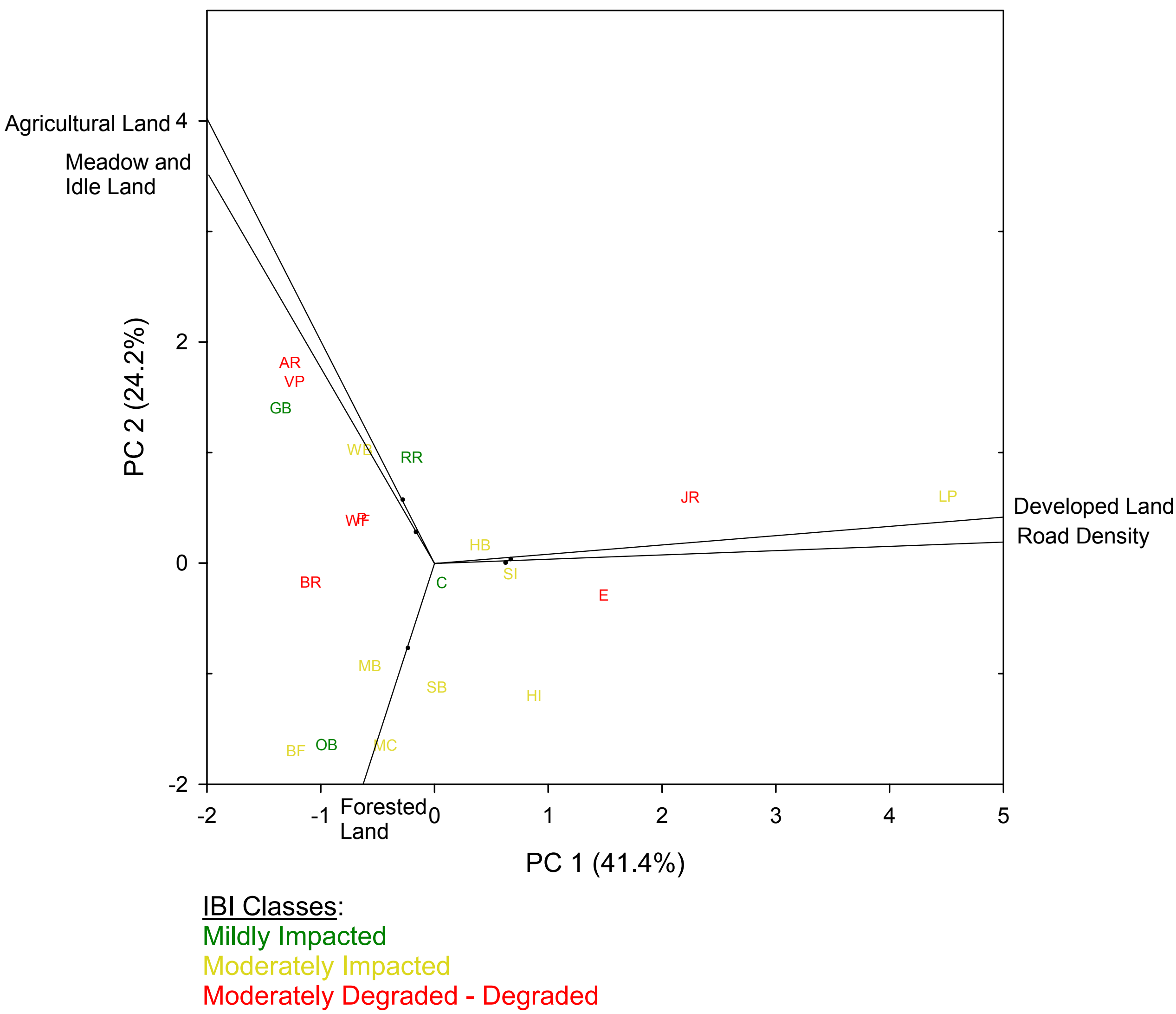

Figure 4. PCA of 5 land-use/cover parameters for 20 coastal wetland sites of Lakes Michigan and Huron. See table 4 for site abbreviations.

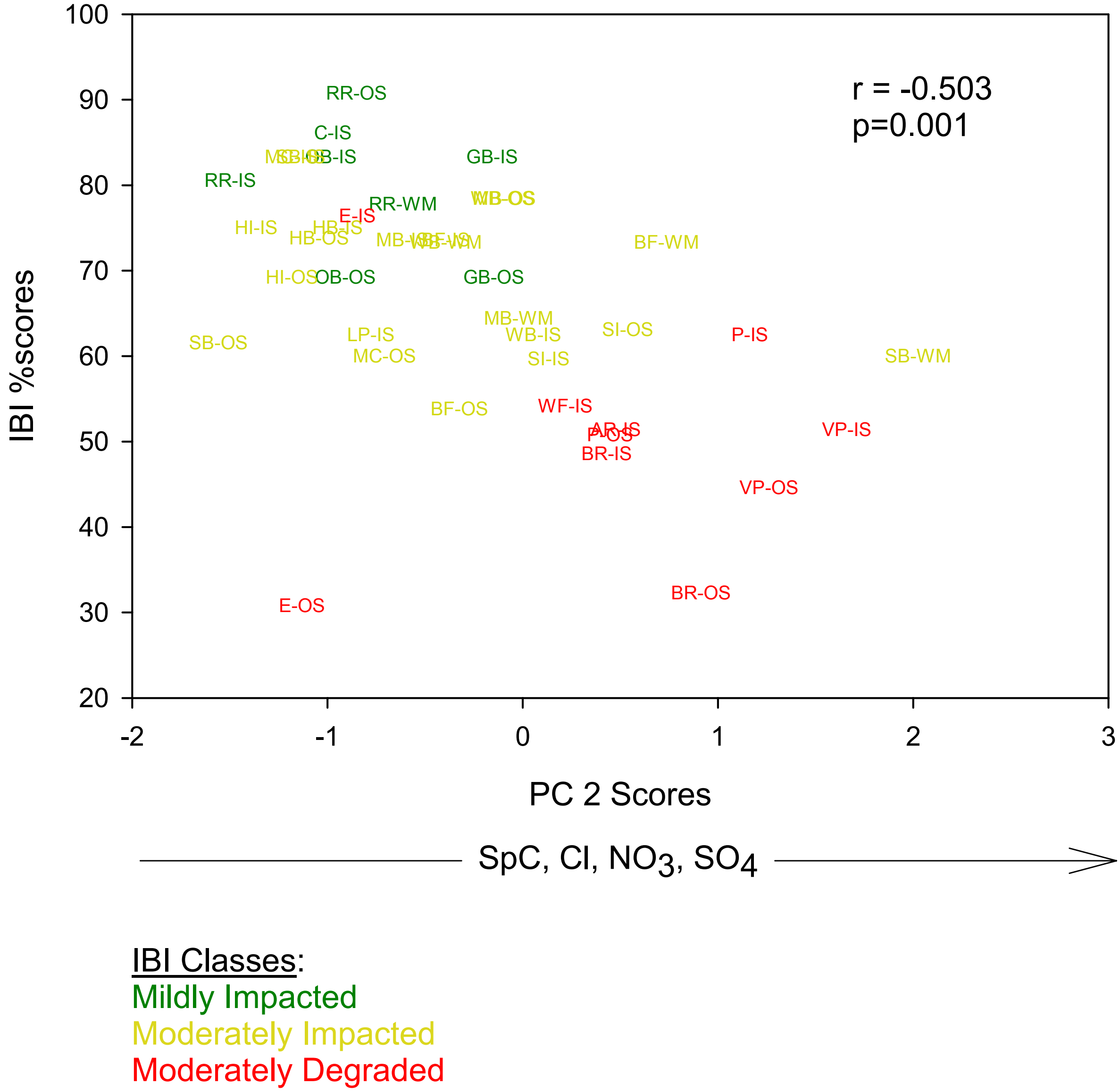

Figure 5. IBI scores (as percent of total possible) for individual vegetation zones vs. principal component 2 scores of the chemical/physical PCA for 20 coastal wetland sites of Lakes Michigan and Huron. See table 4 for site abbreviations.

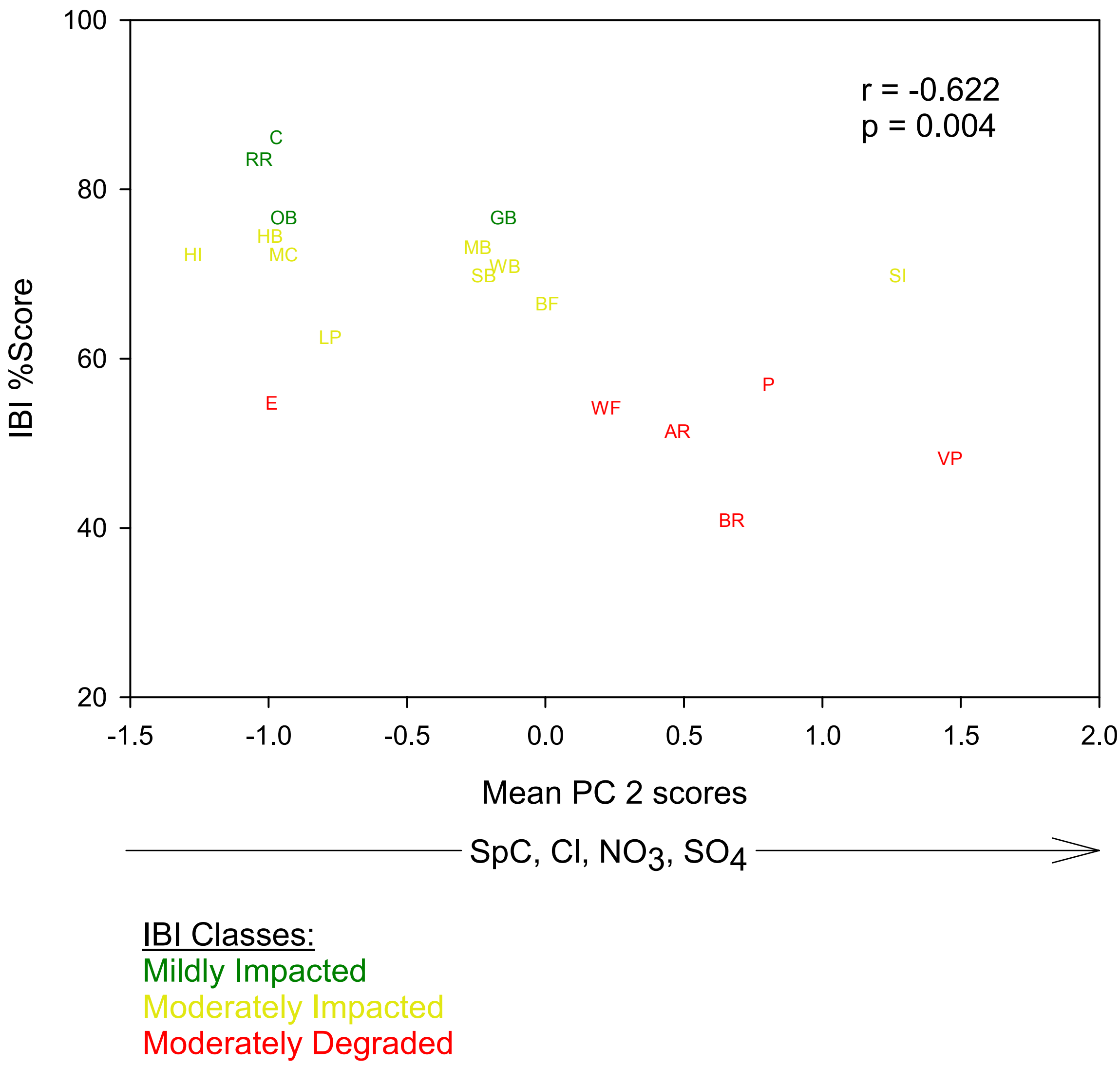

Figure 6. IBI scores (as percent of total possible) vs. principal component 2 scores (means of all vegetation zones per site) for 20 wetland sites. See table 4 for site abbreviations

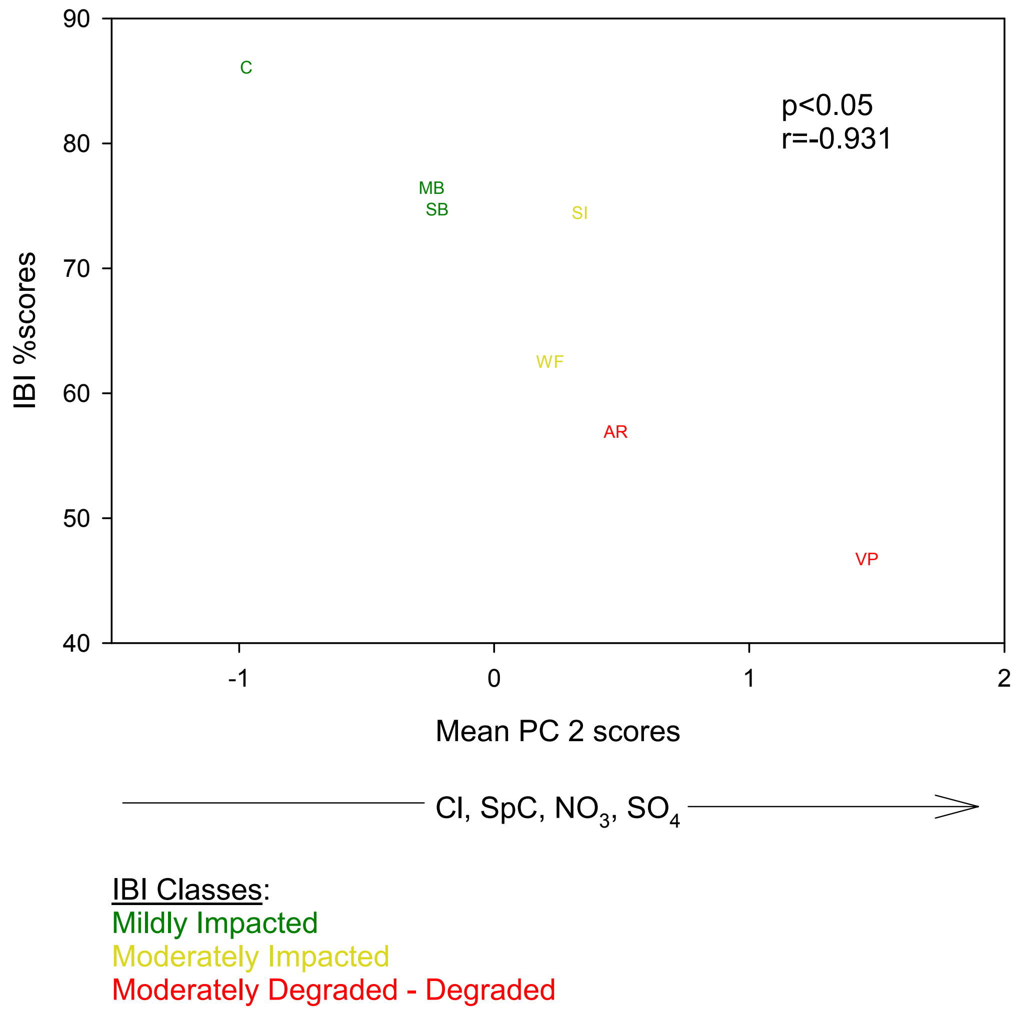

Figure 7. Macroinvertebrate IBI scores for 7 sites using data at lowest operational taxonomic unit in responce to water quality measured by mean PC 2 scores (mean of all vegetation zones per site) of the chemical/physical PCA conducted on data from 20 wetland sites of Lakes Michigan and Huron. See table 4 for site abbreviations.

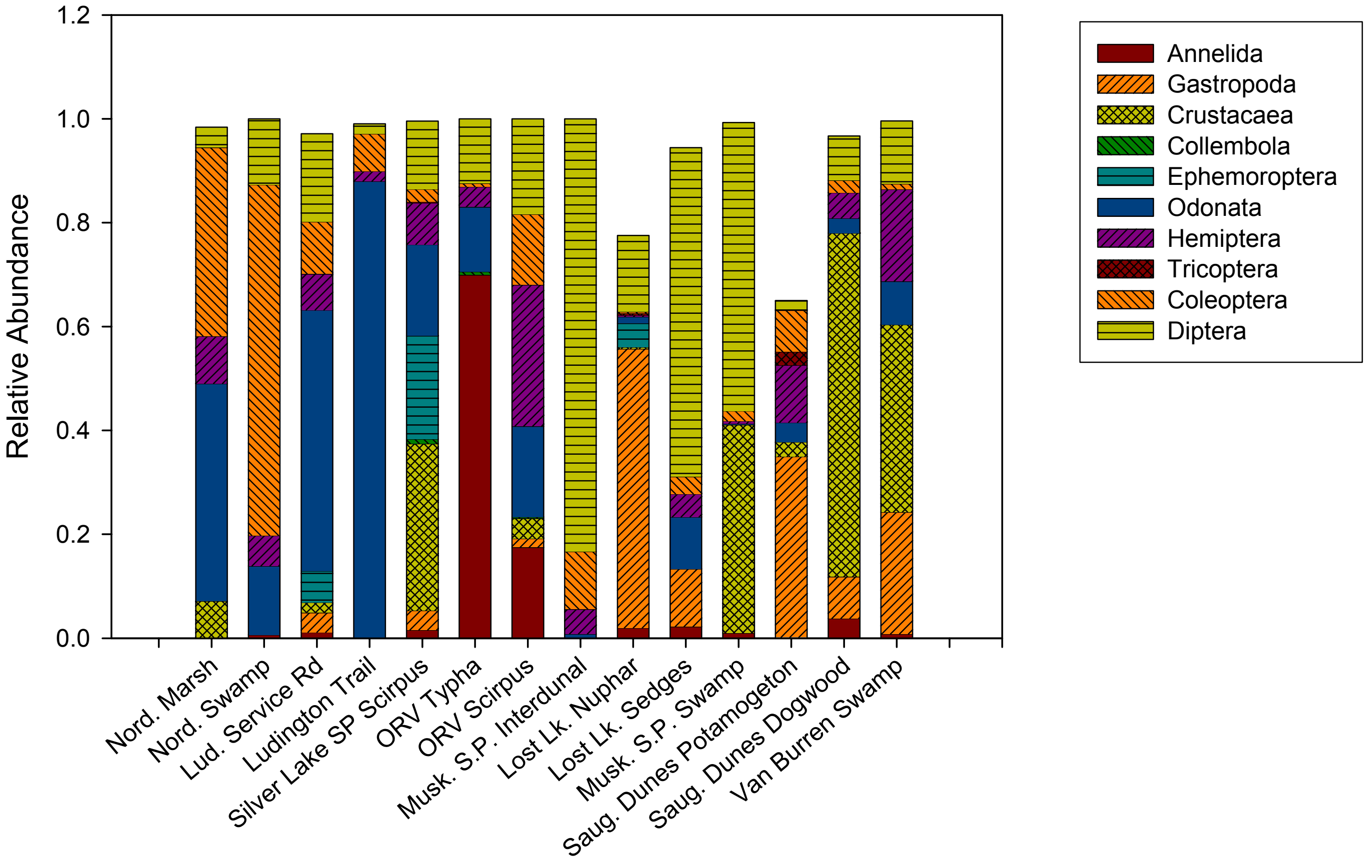

Figure 8. Relative abundances of macroinvertebrates from 10 coastal zone depressional wetlands (14 habitat zones).

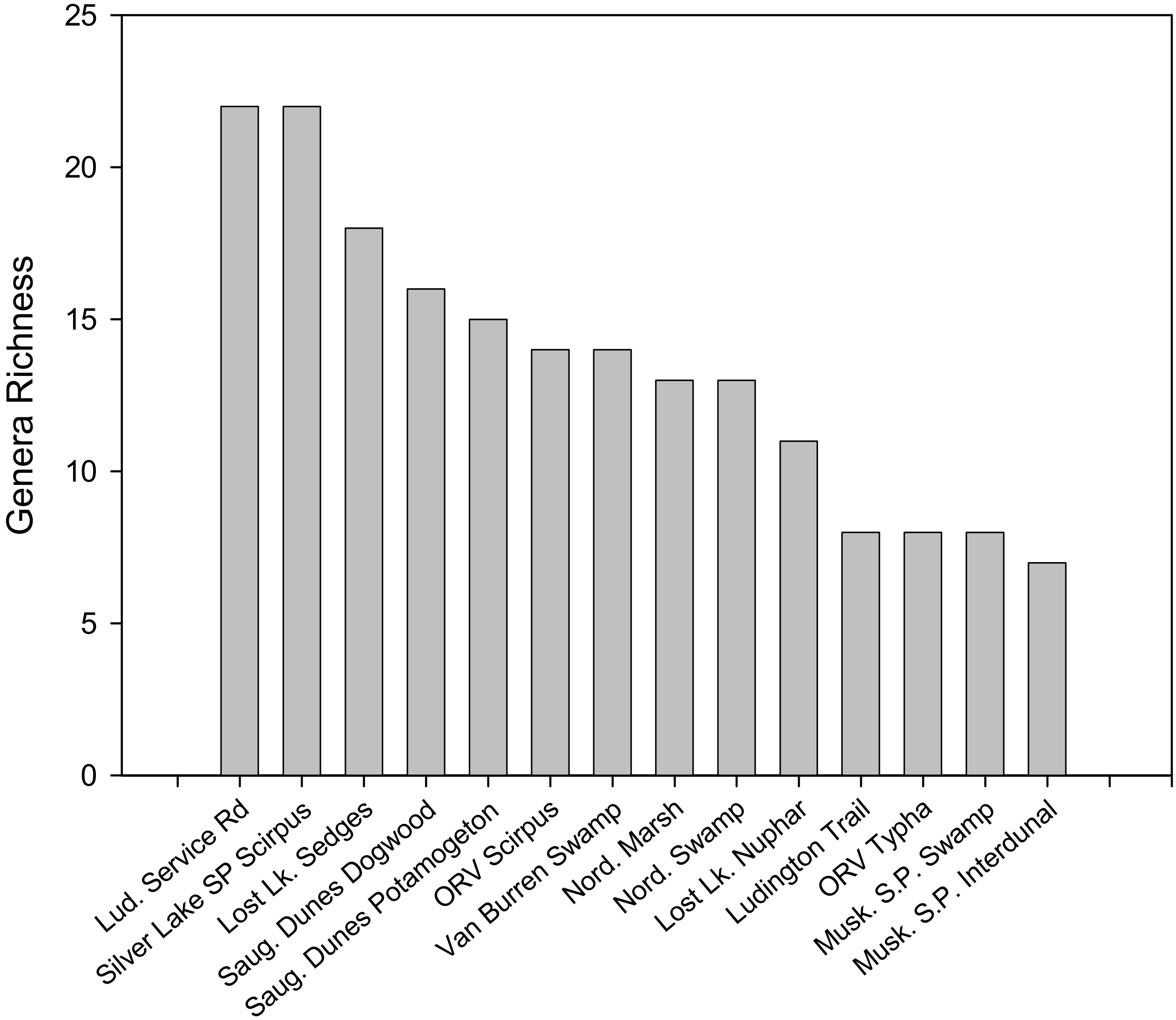

Figure 9. Genera Richness for 10 depressional wetland sites (14 habitat zones) sampled in 2002.

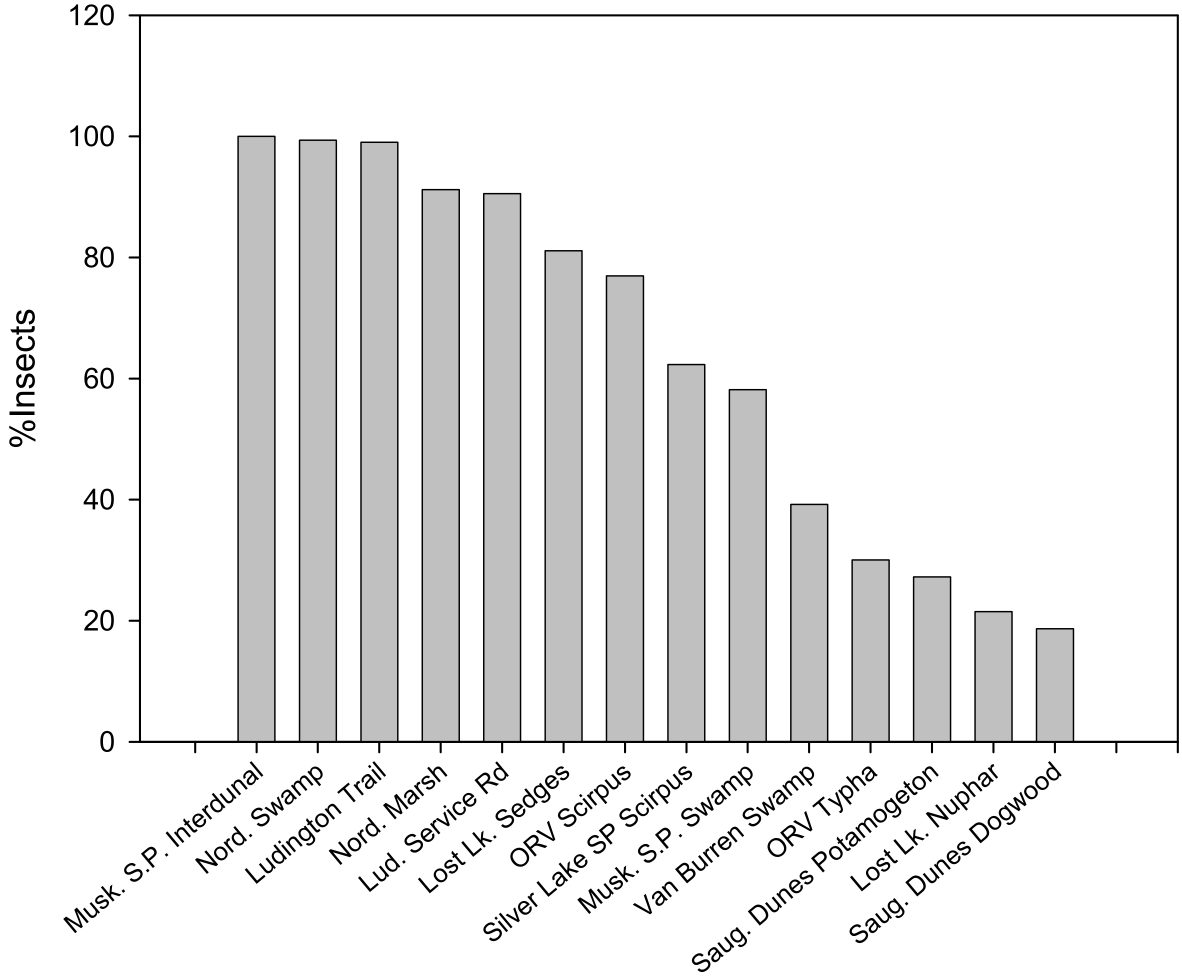

Figure 10. %Insects for 10 depressional wetland sites (14 habitat zones) Sampled in 2002.

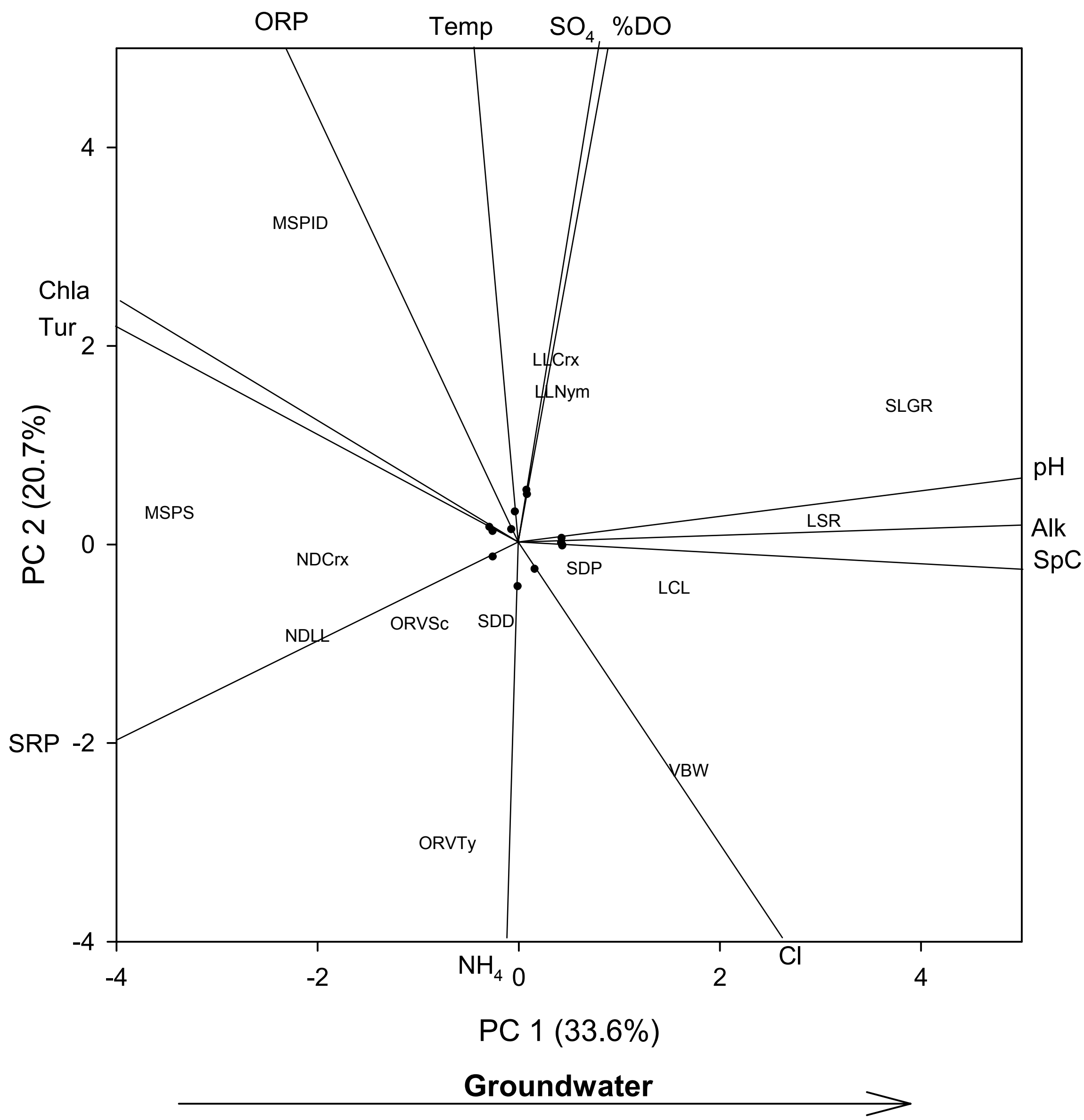

Figure 11. PCA of 12 chemical/physical parameters from 10 coastal depressional wetlands (14 habitat zones).

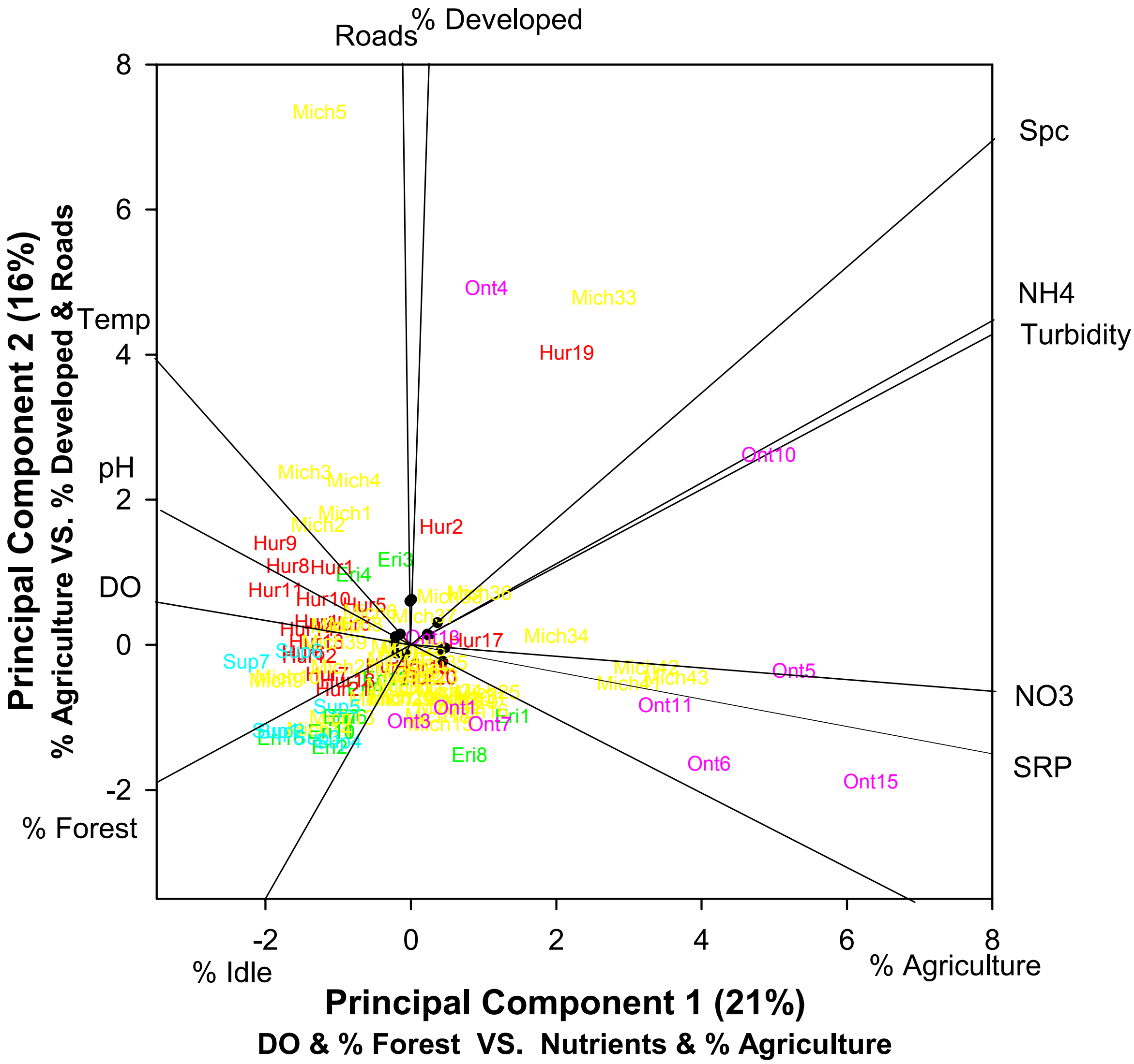

Figure 12. PCA of chemical/physical and land-use/cover parameters for 61 Great Lakes coastal wetland sites.

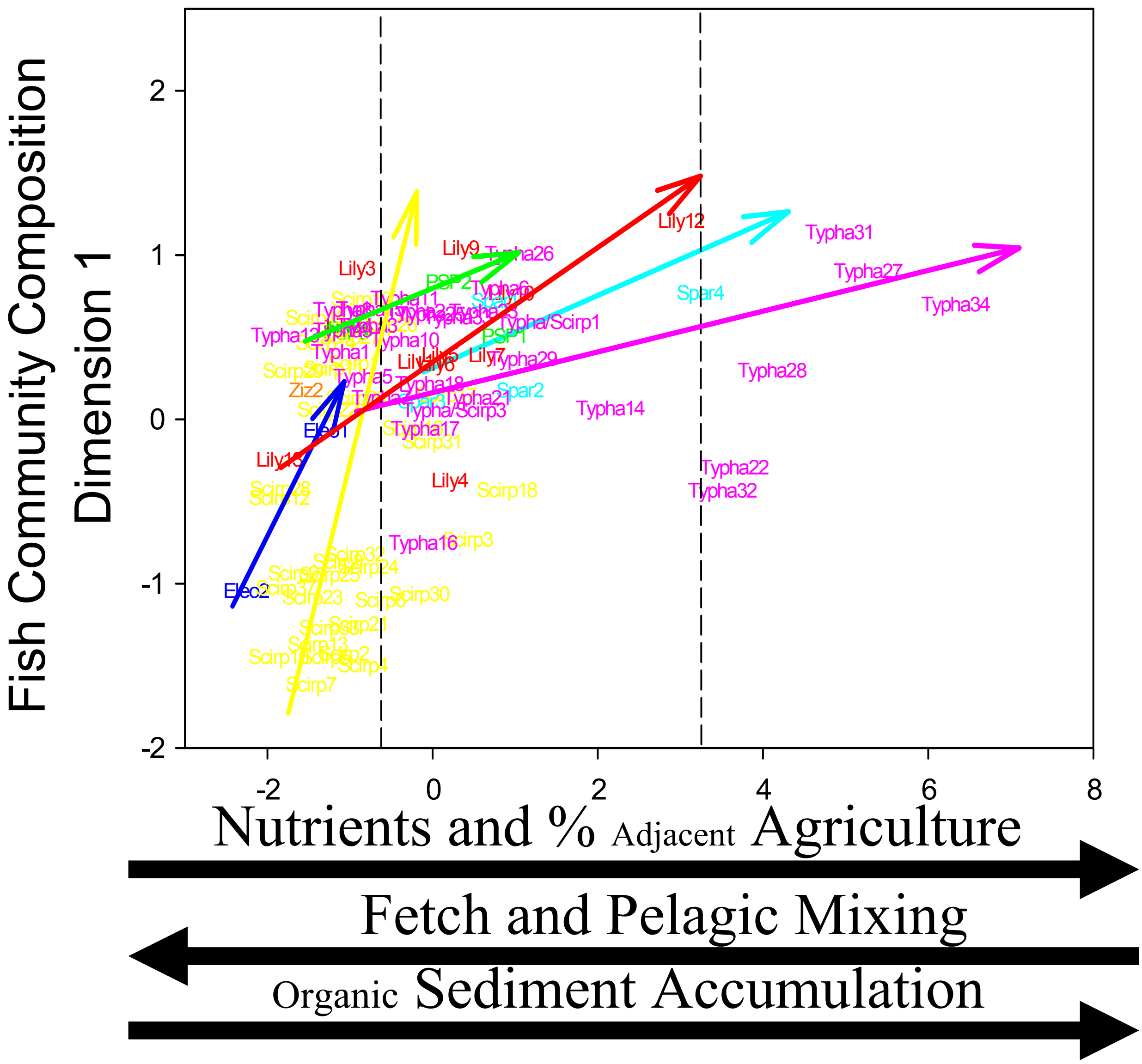

Figure 13. Correlation of fish community composition (Dimension 1 of the correspondence analysis) and abiotic data (PC 1 of the principle components analysis).

- Banded Killifish
- Pugnose Shiner
- Redear Sunfish
- Smallmouth Bass
- White Sucker
- Yellow Perch

- Brook Silverside
- Brown Bullhead
- Fathead Minnow
- Golden Shiner
- Green Sunfish
- Spotfin Shiner

Nutrients and % Adjacent Agriculture

Fetch and Pelagic Mixing

Organic Sediment Accumulation

Figure 14. General trend in fish community Structure.